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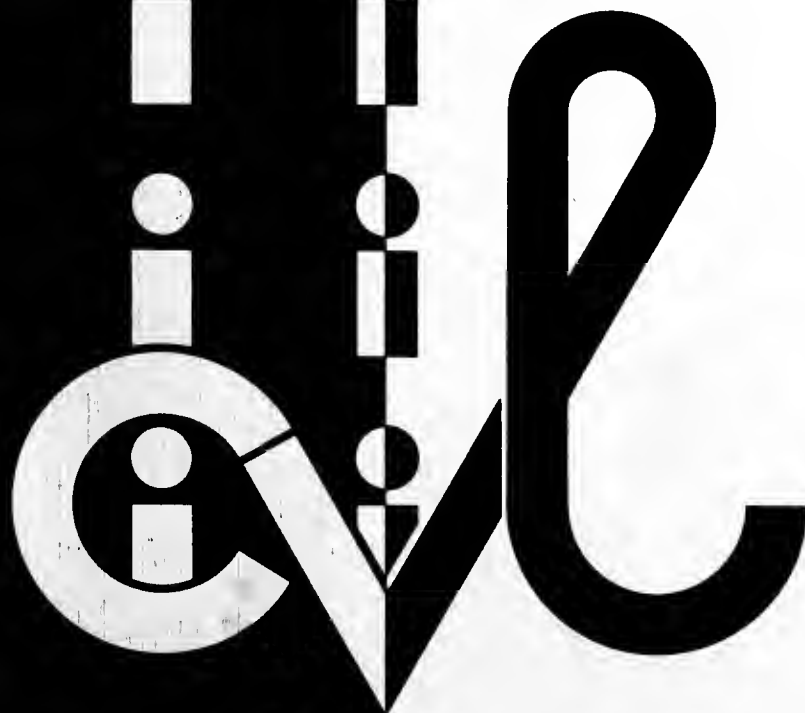
FHWA/IN/JHRP/94/10

Final Report

IMPLEMENTATION OF THE DEVELOPED
QUALITY ACCEPTANCE SYSTEM FOR
STEEL BRIDGE PAINTING CONSTRUCTION

Luh M. Chang

Machine Hsie



PURDUE UNIVERSITY

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1. Report No. FHWA/IN/JHRP-94/10		2. Government Accession No.		3. Recipient's Catalog No.	
4. Title and Subtitle Implementation of the Developed Quality Acceptance System for Steel Bridge Painting Construction				5. Report Date December 30, 1994	
				6. Performing Organization Code	
7. Author(s) Luh M. Chang Machine Hsie				8. Performing Organization Report No. JHRP-94/10	
9. Performing Organization Name and Address Purdue University School of Civil Engineering West Lafayette, IN 47907				10. Work Unit No.	
				11. Contract or Grant No. Indiana HPR-2067	
12. Sponsoring Agency Name and Address Indiana Department of Transportation State Office Building 100 N. Senate Ave. Indianapolis, IN 46204-2249				13. Type of Report and Period Covered Final Report July 1, 1993 - Dec. 30, 1994	
				14. Sponsoring Agency Code	
15. Supplementary Notes					
16. Abstract <p>The purpose of this research is to implement the steel bridge painting quality acceptance system developed in the Joint Highway Research Project HPR-2029-89-27 and to computerize the developed system into inspectors' daily practice.</p> <p>A training program was conducted. Field experiment of the developed inspection system was initiated immediately right after the inspector training program. The new acceptance system was manually tested. Feedback from INDOT's inspectors and other personnel were adopted to refine the inspection system. Meanwhile, an interactive computer graphic program was developed to assist the INDOT in designing the double sampling plan and deciding the sample size with controlled risks for both the INDOT and painting contractors. In addition, a pen-computer system for painting quality acceptance has been developed. It reduces both the need for inspectors' statistical background, and tedious manual paper work. The collected data will be more accurate, timely and providing the INDOT with more information to make better decisions. The electronic network system to transfer data between construction sites and the INDOT's central office was also tested. Once the data are collected in the field, the data inside pen-computers can be transferred to PCs in the central office. The communication between field and office was enhanced.</p> <p>The pen-based computer system developed in this project can be applied to many other highway inspection areas, such as bridges and pavement inspections. Many current inspection works are very time-consuming and may cause errors when the data is re-typed into computers. If the existing inspection forms can be computerized through hand-writing recognition technology, the required efforts and paper shuffling can be largely reduced.</p>					
17. Key Words Quality Assurance Inspection Statistical Acceptance Plan Bridge Painting Pen-Based Computers			18. Distribution Statement No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22161		
19. Security Classif. (of this report) Unclassified		20. Security Classif. (of this page) Unclassified		21. No. of Pages 107	
				22. Price	

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FOR STEEL BRIDGE PAINTING CONSTRUCTION

Luh M. Chang
JHRP Research Engineer
Purdue University

and

Machine Hsie
Research Assistant
Purdue University

Joint Highway Research Project

Project No: C-36-26H
File No: 4-4-8

Conducted in cooperation with the
Indiana Department of Transportation
and

Federal Highway Administration

The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views of policies of the Federal Highway Administration and the Indiana Department of Transportation. This report does not constitute a standard, specification or regulation.

Purdue University
West Lafayette, IN 47907
December 30, 1994

DISCLAIMER

Many competent men and women serve the painting industry; however, in this report, masculine pronouns are occasionally used in reference to engineers, technicians and other personnel. This convention is intended to avoid awkwardness in style and in no way reflects sexual bias on the part of the authors.

All reasonable care has been taken in the preparation of this Manual. However, the Federal Highway Administration can accept no responsibility for the consequences of any inaccuracy or omission. The Federal Highway Administration does not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered necessary to the object of this publication.

Implementation Report

Under the Joint Highway Research Project HPR-2029-89-27, statistical quality acceptance systems have been developed. Nevertheless, the benefits from the research results cannot be fully realized until the systems are incorporated into painting inspectors' daily practice. The purpose of this research is to implement the steel bridge painting quality acceptance system developed in the previous research project and to computerize the developed system into inspectors' daily practice.

A training program was conducted. Field experiment of the developed inspection system was initiated immediately right after the inspector training program. The new acceptance system was manually tested. Feedback from INDOT's inspectors and other personnel were adopted to refine the inspection system. Meanwhile, an interactive computer graphic program was developed to assist the INDOT in designing the double sampling plan and deciding the sample size with controlled risks for both the INDOT and painting contractors. In addition, a pen-computer system for painting quality acceptance has been developed. It reduces both the need for inspectors' statistical background, and tedious manual paper work. The collected data will be more accurate, timely and providing the INDOT with more information to make better decisions. The electronic network system to transfer data between construction sites and the INDOT's central office was also tested. Once the data are collected in the field, the data inside pen-computers can be transferred to PCs in the central office. The communication between field and office was enhanced.

According to the experiences obtained in this research, the following recommendations are proposed:

1. Finalize the Inspection Forms

The new inspection forms have not yet been formally incorporated into official specification. Further communication between the office and job sites is needed to achieve a common agreement about the new inspection system.

2. Integrate Data Structure Between CRA and Pen-Based Computer System

The benefit of computerization is not only time savings but also improved information integration. Once the information is recorded electronically, the processing effort is made automatically. To optimize this benefit, further investigation is suggested to highly integrate the data structure of the pen-computer and the existing Construction Recorder Administration (CRA) database.

3. Continually Survey the New Computer Hardware

In this research, the preferable pen-computer has been selected. However, because of the tough and harsh operating environment at construction sites, pen computers need to be more durable and feature higher shocking resistance and water-proof standards. It is foreseeable that tight competition among pen-computer manufactures and the rapid advancement of computer technology will bring us more powerful and solid pen-computers with lower prices. INDOT should continually survey the new pen-computer technology before massive purchasing.

4. Conduct More Inspector Training Program

The field trial stage showed that the users need more computer knowledge to operate the developed system. More training is recommended. The short courses should be very helpful in strengthening inspectors' capability. The training program should focus on essential issues, such as how to make decisions to accept or reject a painting job, how to ask contractors to fix defective jobs, and how to process

the inspection paper work.

5. Apply Pen-Based Computer Systems To Other Highway Construction Inspection Process

The pen-based computer system in this project can be regarded as pilot research for other INDOT's *field inspection processes*. This technology can be also applied to many other inspection areas, such as bridges and pavement inspections. Many current inspection works are very time-consuming and may cause errors when the data is re-typed into computers. If the existing inspection forms can be computerized through pen-technology, the required efforts can be reduced, eliminating paper shuffling. Further evaluation needs to be conducted for many other inspection processes that are candidate areas for adapting the hand-writing recognition technology.

In summary, the pen-based computer system developed in this project can be applied to many other highway inspection areas, such as bridges and pavement inspections. Many current inspection works are very time-consuming and may cause errors when the data is re-typed into computers. If the existing inspection forms can be computerized through hand-writing recognition technology, the required efforts and paper shuffling can be largely reduced.

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Chapter 1 Introduction

1.1 Problem Statements

The current Indiana Department of Transportation (INDOT) standard specification is inadequate to ensure the quality of current painting construction. The specification, a guide to the inspectors' practice, does not specify: 1) where to take measurements; 2) how many measurements are needed to make acceptance decisions; and 3) what quality level is acceptable. As a result, the inspections are largely based on the inspectors' personal judgments, thus making the acceptance or rejection of the painting project based on an ambiguously-defined inspection process.

To solve these problems, a research project was conducted. Under the Joint Highway Research Project HPR-2029-89-27, statistical quality acceptance systems have been developed. Meanwhile, a set of step-by-step checklists (inspection forms) and control charts were developed to fulfill the proposed acceptance systems. These checklists and control charts can serve as a manual for inspectors' daily work plans. With them, the inspectors know where to inspect, how many measurements are necessary, and how to make acceptance/rejection decisions. Nevertheless, the benefits from the research results cannot be fully realized until the systems are incorporated into painting inspectors' daily practice. Before adopting the new systems, inspectors need to be trained and the potential problems need to be solved. Efforts need to be made to ensure efficient implementation of the new systems.

1.2 Objective of the Study

The purpose of this research is to implement the developed quality acceptance system into INDOT steel bridge painting projects. To reach this goal, the following

objectives must be achieved:

1. To teach painting inspectors the basic quality control concepts and corresponding statistical background.
2. To acquaint painting inspectors with the quality acceptance system developed in the Joint Highway Research Project HPR-2029-89-027.
3. To apply the developed quality acceptance system into INDOT current steel bridge painting projects and refine it into implementable inspection procedures.
4. To construct a computer system for facilitating and simplifying painting inspectors' operation for steel bridge painting projects.
5. To test the developed computer system on current painting projects and incorporate it into inspectors' daily practice.

1.3 Background

Corrosion has been the major threat to steel bridge structures. To date, it is well established that corrosion is the result of an electrochemical process involving an anoxic reaction. During this reaction the metal goes into solution as an ion, and a cathodic reaction takes place. Because of steel's natural tendency to return to its original state after it has been extracted from its ore, the steel reacts with its environment and corrodes. The process of corrosion requires four elements, including 1) an anode, 2) a cathode, 3) an electrolyte, and 4) a conductor. Only when these four components are present at the same time can corrosion occur. Methods such as protective coatings and cathodic protection protect steel against corrosion by eliminating one or more of the above elements. Steel contains both anodes and cathodes, due to grain boundaries, grain orientation, thermal treatments, surface roughness, and strains. Additionally, steel serves as an efficient conductor. Atmospheric moisture serves as an electrolyte. Without protection, corrosion will thus occur on steel structures.

To prevent corrosion on steel bridges, highway agencies have spent several hundred million dollars every year painting them. However, many painted steel bridges have been failing prematurely, and highway departments have not adequately protected the nation's bridges against corrosion (Appleman, Bernard R., 1988). As a result, Purdue University and INDOT cooperated with the Federal Highway Administration to develop an efficient quality assurance system for bridge painting contracts (Chang, Luh-Maan and Hsie, Machine, 1992b).

The INDOT is now using a recipe type of specification to control bridge painting quality. This type of specification includes details such as: materials to be used, surface preparation, paint application, and so forth (Indiana, 1988). Inspections of materials and work are required at various stages of painting before acceptance. With the many variables involved in the painting process, the current specification does not always guarantee the quality of the final painting product. Painting quality could be better assured by allowing the contractors to control more of their operation, and by having INDOT place its emphasis on specifying and checking the end-results. That is, the contractors would take more responsibility for quality process control, and INDOT would assume the responsibility for specifying the quality requirements and the acceptance criteria, and by inspecting the products. This type of specification, with better allocation of the responsibility between owners and contractors, is designated Quality Assurance (QA) or End-Result Specification.

To solve the aforementioned problems, a research project was initiated by INDOT under the Joint Highway Research Project HPR-2029-089-27. The purpose of this research was to develop a QA specification for steel bridge painting constructions. The research project has been completed and was approved by the JHRP board on April 22, 1992.

The research unveiled many pitfalls that interfere with obtaining adequate quality for INDOT's steel bridge painting. Several possible solutions were proposed. The

acceptance plan was developed and incorporated into a format of step-by-step check lists (inspection forms) and control charts. Also, the existing specification was revised based on the knowledge obtained from the research.

Statistical sampling systems are the core of QA specifications. In the research, four statistical sampling systems were constructed for painting contracts including 1). Quality Index Sampling System, 2). Variable Single Sampling System, 3). Attribute Double Sampling System, and 4). Attribute Proportion Sampling System (Chang, Luh-Maan and Hsie, Machine, 1992a). Among the four systems, the Attribute Double Sampling System (ADSS) was finally adopted and formatted into a set of inspection forms and control charts. The inspection forms and control charts can be divided into four stages including 1) Pre-inspection Stage, 2) Surface Inspection Stage, 3) Priming Stage, and 4) Top/Intermediate Coating Stage. It covers detailed inspection steps, supplying a precise guide to inspectors' daily practices. Meanwhile, a computerized system is proposed to reduce the tedious paper work and the need for inspectors' statistical background to process inspection data. With the power of computers, advanced statistical acceptance systems could be programmed into software. The system will allow the inspectors to simply input the results of their measurements, and the decisions are automatically made by the computer. With the help of the computer, an efficient, feasible and paperless inspection process can be achieved.

1.4 Work Plan

The steps for accomplishing the goals of this project can be outlined as follows:

Task 1. Conducting Inspector Training Session

First, the basic statistical concepts for quality control and acceptance systems will be introduced. Herein, the terms of lot, sampling size, single/double sampling,

attribute/variable sampling, operating characteristic curve (OC curve), producer's/owner's risks, and quality index will be covered. In addition, numerical examples with application to steel bridge painting inspection will be demonstrated. Second, the step-by-step checklists (inspection forms) and control charts developed in the previous research project will be presented. The use and benefits of the checklists will be clearly explained.

Task 2. Manual Implementation of the Developed System

After the inspectors obtain the principles and theories behind the quality acceptance plans, new painting projects will be accessed with help from INDOT. Field experiments will be set up. The double sampling method will be manually tested. Feedback from INDOT inspectors and other personnel will be solicited. Based on the feedback, the inspection system will be refined to an implementable and effective system.

Task 3. Computerization of the Developed System

A computer program for the developed quality acceptance system can reduce the need for inspectors' statistical background and tedious paper work. In this task, the data input of field measurements and statistical data process will be computerized. The application of pen-based computers is proposed to break the barriers in transmitting computer technologies into painting construction sites. The acceptance or rejection decision needs to be automatically made right after data are entered into the computer.

Task 4. Training for the Computer System

Since many INDOT inspectors do not have enough experience to handle computers, basic training is necessary to introduce computer technology to them.

Inspectors will be taught how to apply the developed computer inspection program through desktop computers and pen-computers. The program is expected to include data input, data processing and filling out inspection forms.

Task 5. Implementation of Computer Program

Once the inspectors have adequate experiences to apply the developed computer program, the program will be tested in both fields and offices. Again, feedback regarding friendliness and simplicity for using the program will be collected to continuously refine the program.

Task 6. Electronic Networking between Fields and the Central Office

With the increased use of computers in almost every discipline, the need to access or share information among users has surfaced. In this task, electronic networks connecting INDOT's central office and fields will be investigated.

Task 7. Final Report

A technical report will be prepared and submitted to INDOT for final approval. The methodologies used, developed computer system, references cited, and experience obtained from the research will be compiled in the final report. Meanwhile, a balanced viewpoint of shortcomings and benefits of using the acceptance plans and their corresponding computer programs will be detailed in the report.

1.5 Structures and Contents of the Report

This report is divided into seven chapters reflecting specific subject areas.

Chapter 1 provides a general introduction that addresses the need for the research and its

major tasks. The benefits of the research are also noted.

Chapter 2 explains the methodology used to fulfill the goal of the project.

Chapter 3 gives a deeper review of the attribute double sampling method. Also, an interactive computer graphic program is introduced to facilitate design work of the attribute double sampling plan.

Chapter 4 describes the course of the field test in the new inspection system. The pros and cons of the system are also summarized.

Chapter 5 presents the inspector training program conducted by the INDOT and Purdue University.

Chapter 6 contains detailed information about the developed pen-based computer system.

A recommendation for applying the new computer technology is proposed.

Chapter 7 concludes the findings in this research, and proposes further research areas that could be beneficial to INDOT.

Chapter 2 Methodology

2.1 Four Major Tasks

The methodology used in this research is shown in figure 2. There are four major tasks including:

1. Development of Interactive Computer Graphic Program for Attribute Double Sampling
2. Field Trial for Inspection Forms
3. Inspector Training Program
4. Development of Pen-Computer System

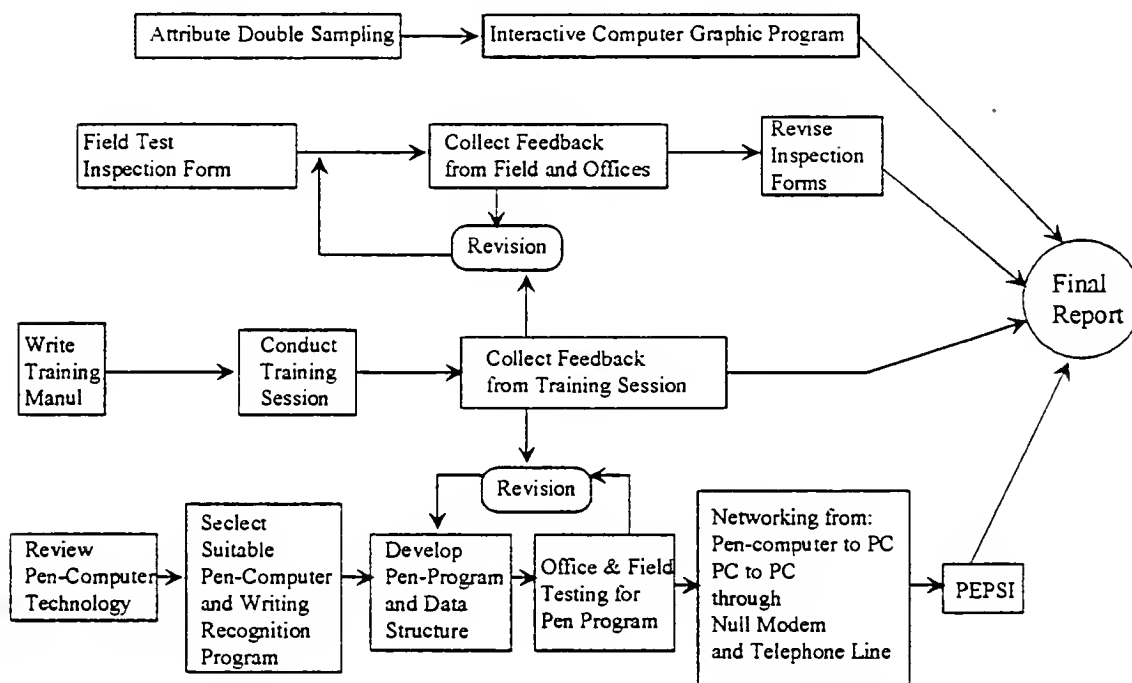


Figure 2.1 Methodology and Major Tasks of the Research

2.2 Interactive Computer Graphic Program for Attribute Double Sampling

In the previous research, the double sampling acceptance plan was developed which could be summarized in the following equation:

$$Pa = P(x_1 \leq c_1) + \sum_{i=c_1+1}^{r_1-1} P(x_1 = i) \cdot P(x_2 \leq (c_2 - i))$$

The Pa is a function of six parameters: n_1 , n_2 , c_1 , r_1 , c_2 , and pd , that is $Pa = F(n_1, n_2, c_1, r_1, c_2, pd)$. To design a desired double sampling plan, different combinations of the five parameters: n_1 , n_2 , c_1 , r_1 , c_2 are evaluated and printed out as a double sampling design tables (please refer to the appendixes of the previous project report). With this table, the current attribute double sampling method was developed, which has the parameters of $n_1=10$, $n_2=10$, $c_1=1$, $r_1=3$, and $c_2=4$ (For details, please refer to Chapter 3).

In the future, because of the evolution of painting technology, the required quality levels may change. With this table, INDOT will be able to re-design the sampling system by choosing another set of parameters to meet their desired quality levels. However, because of the complexity of the equation and its many parameters, it is difficult to choose the five parameters for designing a desired double sampling. No monograph table is currently available for designing the double sampling plan. To solve this dilemma, an interactive computer graphic program was developed to assist in the design of the double sampling system.

The computer graphic program was developed to allow the users to interactively design the double sampling plan. Before using this program, the user should have a set of AQL -- α risk, and RQL -- β risk requirements in their minds. Using this program, users simply assign non-negative integers to the five parameters n_1 , n_2 , c_1 , c_2 , and r_1 , and the resulting OC curve will be shown on the screen. Adjusting the five parameters will change

the OC curves correspondingly. The users interactively change the five parameters until they find a reasonable OC curve. With this program, INDOT can conveniently re-design the current attribute double sampling plan by selecting different combinations of acceptance parameters: n_1 , n_2 , c_1 , r_1 , and c_2 . Also, this program can be used to design double sampling systems for other inspection practices such as pavement and material inspection.

2.3 Field Trial of the Developed Quality Acceptance System

To enhance the applicability of the developed quality acceptance system, the researchers visited job sites and conducted interviews with inspection teams. Researchers observed how the inspection forms were used. Knowledge and critical feedback were obtained from inspectors to modify the QA contents and the inspection forms.

2.4 Inspector Training Program

Benefits from the previous research results cannot be fully realized until the systems are incorporated into inspectors' daily practices. To adopt the new systems, inspectors need to be trained. Therefore, the INDOT central office and Purdue University held a painting inspection training program to introduce the new inspection system. The training program was held in the Indiana Government Central North Building at the end of May 1992. Ten bridge painting inspectors from six different districts attended the training program. A simple but useful training manual was written for the training program shown in Appendix D. Feedback was collected from those who attended for future revision of the inspection forms and the pen-computer program.

2.5 Development of Pen-Computer System

The steps for accomplishing this goal are outlined as follows:

- Task 1. To investigate the pen-based computer technologies and select suitable software and hardware.
- Task 2. To develop the pen-computer program incorporating the new steel bridge painting inspection system.
- Task 3. To test the pen-computer system in both fields and offices, and revise the program.
- Task 4. To test network for data transfer among construction sites (pen-computers), local offices (Desk Top PCs) , and the central office (Desk Top PCs).

Chapter 3

Attribute Double Sampling and Interactive Computer Graphic Program

3.1 Background

The Attribute Double Sampling System (ADSS) is a type of acceptance sampling plan. The acceptance sampling plan (ASP) applies statistics to quality inspection. The key function of the ASP is to guide the decision to accept or reject finished products. There are several ways to categorize acceptance sampling plans. In terms of the number of samples taken, they can be classified as single or double sampling. Based on the way the sampling information is utilized, they can be classified as attribute or variable sampling. Among the many acceptance sampling methods, the Attribute Double Sampling System (ADSS) was finally adopted in this research. In the following section the terminologies: single/double sampling, attribute/variable sampling, operating characteristic curve (OC curve), and producer's/owner's risks are explained to facilitate the readers' understanding.

3.1.1 Single and Double Sampling

In the single sampling plan, samples are taken only once and the decision to accept or reject the lot is made based on this one-time sampling. On the other hand, a double sampling plan uses a smaller sample size; then if the information from the first sample shows that the product obviously conforms to the specified requirements, the lot is accepted. However, if the first sampling shows that the product is obviously not conforming, then the lot is rejected. If the measurement results are between these two situations, and conformance is not clear, a second sampling is done to decide whether the lot will be accepted or rejected. The advantage of double sampling compared with single sampling is that it generally requires smaller sample sizes on the average to obtain the

same efficiency as in single sampling plans (Wadsworth, M. Harrison and Stephens, Kenneth S. A. and Godfrey, Blanton 1986).

3.1.2 Attribute and Variable Sampling

Sampling plans also can be categorized as attribute sampling and variable sampling. A distinguishing characteristic of variable sampling is the requirement of calculating the standard deviation (SD) which can depict the finished product's variations. If the inspectors need to calculate SD in the sampling plan, the plan is a variable sampling plan; otherwise, it is an attribute sampling plan.

An attribute sampling plan usually produces one of two results -- the individual measurement in the sample either conforms or does not conform to the specified attribute. The following example is used to illustrate attribute sampling. The INDOT specification requires that the measurements of primer DFT be no less than 2.5 mils (6.25×10^{-3} cm; 1 mil = one thousandth inch = 2.54×10^{-3} cm). DFT measurements from one lot might be 1.0 and 2.51 mils, and measurements from a second lot 2.48 and 3.5 mils. Using the attribute sampling system, the results are the same for both lots because one out of the two measurements is non-conforming; both would be considered 50% out of the limits. Intuitively, it is obvious that the second lot with readings of 2.48 and 3.5 mils has a higher potential for satisfying the required lower limit of 2.5 mils. However, with an attribute sampling plan, the two sets of readings are the same; both are 50% out of limits. To avoid this weakness, a variable sampling can be used.

A variable sampling plan makes use of more relevant details. Instead of just determining whether an individual sample is within the specified limits, variable sampling utilizes the available data to estimate and represent the underlying population. After the overall population is estimated, a more accurate estimated percent of non-conformance can be acquired. This statistical sampling system allows one to obtain the same level of

discrimination power with smaller sample size (Wadsworth, M. Harrison and Stephens, Kenneth S. A. and Godfrey, Blanton 1986).

3.1.3 Operating Characteristic (OC) Curve

The OC curve is the curve that shows the probability of lot acceptance based on the various quality levels. "One of the most useful considerations of a sampling plan is its operating characteristic (OC) function. Whenever a statistical sampling is derived, its description is not complete until its OC function or OC curve has been described" (Wadsworth, M. Harrison and Stephens, Kenneth S. A. and Godfrey, Blanton 1986a). Figure 3.1 is an example of an OC curve. It shows that when the underlying quality level of the lot is 10% defective (or say 90% conforming) with the specified requirements, by applying a specific acceptance plan, it can be predicted that this lot will be accepted with the chance of 95% (or rejected with the probability of 5%). When the underlying quality level of the lot goes up to 40% defective, the chance of accepting the lot would decrease to 5% accordingly. When the acceptance plan changes, its OC curve will change also. Therefore, by setting a proper acceptance sampling plan for lots with different quality levels, the probability of accepting or rejecting the lots could be controlled and predicted.

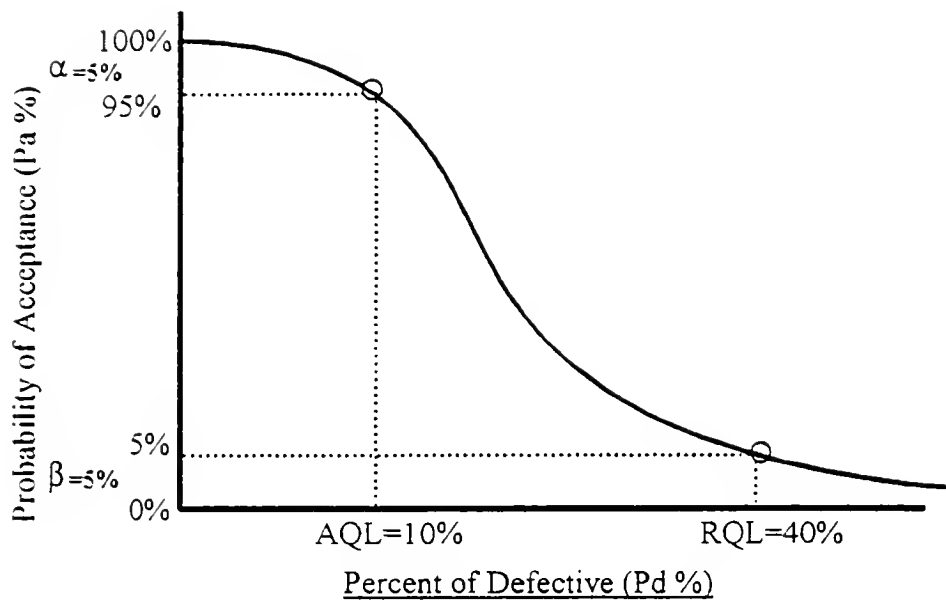


Figure 3.1 Typical Operating Characteristic (OC) Curve

3.1.4 Producer's/Owner's Risks

Contractor-supplied products that the highway agencies are willing to accept are designated as acceptable quality level (AQL). However, because of the variation of sampling, it is not 100% guaranteed that all the samples taken from these AQL products will lead the highway agencies to accept the products.

Products that highway agencies are very sure to reject are designated as rejectable quality level (RQL). Likewise, it is not 100% guaranteed that these RQL products will lead the highway agencies to reject the products based on the designed sampling plan. The chance of rejecting AQL products is the producer's risk designated as alpha (α) risk. The probability a RQL product will be accepted is the owner's risk, designated as (β) risk. Please refer to Figure 3.1.

According to Statistical theory, a more precise estimate of quality can be obtained with larger sample sizes, thus reducing the risk of making a wrong decision. However, larger sample sizes will increase the cost of inspection. How can people strike a balance between accuracy and cost? The solution is to analyze and control the risk for making a

wrong accepting-rejecting decision. Therefore, many acceptance plans are developed based on controlling the α -AQL and β -RQL risks. In other words, these acceptance plans are designed to obtain the desired OC curves.

Quality acceptance plans vary because different statistical theories and combined quality parameters are applied to derive the decision criteria. In this research, four different systems were developed. Only attribute double sampling system is discussed in this paper.

3.2 Reasons for Adopting Attribute Double Sampling System (ADSS)

As mentioned before, several statistical acceptance sampling systems are available such as the four acceptance sampling systems including: a). Quality Index Sampling System, b). Variable Single Sampling System, c). Attribute Double Sampling System, and d). Attribute Proportion Sampling System (Chang, Luh-Maan and Hsie, Machine, 1992a).

Each of four acceptance sampling systems has advantages and disadvantages. How can the highway agency choose the most suitable acceptance sampling system to develop the QA specification? Unfortunately, there is no easy answer to this question, because none of the above acceptance systems fits every kind of inspection condition. Choosing the best acceptance sampling system depends on the features of the inspection process that may concern the cost of measurement, the required accuracy of decision, the facility available, the imposed time constraints, and so forth. The following three reasons make the attribute double sampling a preferable sampling system for highway steel bridge painting construction.

a). Simplicity

In general, the variable sampling plan can better utilize the information carried by the data to provide a more accurate estimate. Therefore, the variable sample system was

originally developed in this research. However, a serious problem was encountered during the testing stage. In order to apply the variable sampling system, the computation of statistical parameters such as standard deviations is necessary. After interviews with many INDOT inspectors, it was found that "inspectors commonly don't have enough statistical background" to run the variable sampling. Due to this limitation, the variable single sample plan was not executable. On the other hand, the ADSS has the advantage of being easy to use. To apply the ADSS, the inspectors do not need any statistical background.

Ideally, if the poor quality can be detected at early stage, remedies can be made before too many unqualified products are produced (Gentry, Claude. and Yrjanson, William A, 1987). To do so, the acceptance sampling system should be able to provide real-time or rapid decision making. For this reason, the ADSS are recommended. They are easy to use by just counting the number of defective items. No tedious calculation is involved and the decision to accept or reject can be made right after the measurements are taken. As an example, the profile of steel surface is one important quality parameter in steel painting. If the unqualified sand-blasted surface can be detected rapidly by a "real-time" acceptance sampling system, the nozzle or air-pressure can be adjusted right after the defects are found. Although the above processes belong to quality control, which should be conducted by contractors, the highway agency may be able gain benefits through the rapid decision of the acceptance sampling system (Crosby, Philip B., 1979).

Another benefit of the rapid decision making of the ADSS is that it reduces construction delays due to the interruption of inspection. Many inspection processes currently require hold points in the course of construction to inspect the quality. If the acceptance decision can be obtained rapidly, construction can be continued without too much delay.

Inspectors at construction sites need to carefully check many work processes. For example, during this research, it was found that field painting inspectors have to monitor the mixture of paint material, the air versus steel temperature, the traffic control and so on.

Dealing with tedious data processes, such as calculating the standard deviation, impose an extra work load on the inspectors, and the inspectors may lose their concentration on other essential inspections. For this reason, the data process should be as easy as possible and the ADSS is recommended.

b). Flexibility

To use a variable sampling system, all the quality parameters need to be quantified. However, in a real situation, many inspection factors can not be quantified. For example, coatings with bubbling or mud-cracking are serious defects in painting application. However, these types of defects are visible only and very difficult to be quantified. On the contrary, the ADSS does not have the above constraint, because it can be used in non-quantified parameters.

Some inspection procedures should combine more than one quality parameter in one single decision making. For example, for steel surface preparation, the surface cleanliness should comply with the SSPC-6 grade; meanwhile, the profile should be within 1.5 mils to 3.5 mils. To combine more than one quality parameter into one decision, the ADSS is recommended. When using the ADSS for each single sample, only after all the quality parameters are satisfied, the individual sample is counted as "pass"; otherwise, it is "not pass." More than one attribute can be combined to form one quality parameter. For example, the profile measurement and cleaning grade can be combined to form one quality parameter. In this case, at each measured spot on the sand-blasted steel surface, inspectors may measure the "profile" and visually check the grade of the "cleanliness" at the same time. If either one of the two requirements does not conform, the measured spot is counted as defect.

In addition, many inspection practices need to check not only the lower but also the upper limits for certain quality parameters. Two-sided limits are not uncommonly required in construction inspection. For example, painting inspectors need to check the

profile of the sand-blasted steel surface to make sure that the profile is large enough and not less than the 1.5 mils needed to provide adhesive mechanism to paint material; additionally, it must be no more than 3.5 mils to allow the paint to cover the peak of the profiles (SSPCM, 1989). The ADSS can easily handle the Two-Sided Limits criteria.

c). Smaller Sample Size

In the double sampling, if the first sampling has a highly conforming result, no further sampling is necessary and the acceptance decision can be made. Likewise, if the first sampling comes out with a very poor conforming result, the rejection decision can be made already. If the first sampling falls between obvious-acceptable and obvious-rejectable conditions, a second sampling should be taken. The advantage of the double sampling system is that it requires smaller sample sizes on the average to obtain the same efficiency as in the single sampling plans. This system can reduce the work load imposed on the inspectors, and make the sampling system more feasible.

3.3 Procedures of Attribute Double Sampling System (ADSS)

The attribute double sampling system (ADSS) utilized two sample sizes along with acceptance-rejection parameters. The notations of the parameters are described as follows:

- n1 :** The required sample size in the first sampling.
- n2 :** The required sample size in the second sampling.
- c1 :** The first acceptable number. If the number of defect (non-conforming items) found in the first sampling is less than or equal to this number (c1), the lot is accepted.
- r1 :** The first rejectable number. If the number of defect found in the first sampling is larger than or equal to this number (r1), the lot is rejected.
- c2 :** The second acceptable number. The parameter is checked when the second sampling is taken. If the total number of defect (including the first and second

sampling) is less than or equal to this number (c_2), the lot is accepted. Otherwise the lot should be rejected.

x_1 : the number of the non-conforming items found in the first sampling.

x_2 : the number of the non-conforming items found in the second sampling.

Using the double sampling system, the inspectors first take the sample with the size of n_1 . If the number of non-conforming measurements (x_1) is equal to or less than the first acceptance number (c_1), the lot is accepted. If the number of non-conforming units is equal to or greater than the first rejection number (r_1), the lot is rejected.

If the non-conforming units fall between c_1 and r_1 , a second sample size of n_2 is taken. The number of non-conforming items found in the second sample is x_2 . If the total non-conforming items ($x_1 + x_2$) from the first and second sampling (totally $n_1 + n_2$ measurements) are less than or equal to the second acceptance number c_2 , the lot is accepted. Otherwise, the lot should be rejected. To sum up, the procedures of this system are:

if $x_1 \leq c_1$ then accept the lot

if $x_1 \geq r_1$ then reject the lot

if $c_1 < x_1 < r_1$ then a second sample of size n_2 should be taken.

When the second sampling is necessary, continue the following processes:

if $x_2 + x_1 \leq c_2$ then accept the lot.

if $x_2 + x_1 > c_2$ then reject the lot.

3.4 Theory of the Double Sampling Acceptance System

According to the statistical sampling theory, if the lot size (underlying population) is finite, the hyper-geometric distribution should be used to describe the probability of the sampling. In other words, if the lot size is much larger than the sample size, the binomial

distribution should be used to calculate the probability of the sampling (Burr, W. Irving, 1976).

In the inspection of steel bridge painting construction, almost infinite numbers of dry film thickness (DFT) measurements can be taken within any one piece of the painted structure member. Consequently, the lot size (underlying population) of the sampling is regarded as unlimited. However, only a few measurements are usually taken to define the quality. For this reason, binomial distribution should be used to develop the sampling system. The notations used in the equations are:

pd : Underlying percentage of non-conforming (percentage of defect).

n : sample size.

x : number of non-conforming found in the sample.

P() : binomial distribution.

Given that the underlying percentage of non-conforming of the product is **pd** (percent of defect), according to the binomial statistics, the probability for getting **x** non-conforming items under the sample size of **n** is (Wadsworth, M. Harrison and Stephens, Kenneth S. A. and Godfrey, Blanton, 1986):

$$P(x) = \frac{n!}{(x!)(n-x)!} pd^x (1-pd)^{(n-x)}$$

For example, assume that the sample size is 10 (n=10), and the underlying percentage of defect is 15% (pd=0.15). By plugging the parameters into the previous equation, the probability of getting three (x=3) non-conforming measurements will be:

$$P(3) = \frac{10!}{(3!)(10-3)!} 0.15^3 (1-0.15)^{(10-3)}$$

$$P(3) = 12.98\%$$

As another example, if sample size is 7 (n=7) and underlying percentage of defect is 25% (pd=0.25), the probability of getting two (x=2) non-conforming measurements will be:

$$P(2) = \frac{7!}{(2!)(7-2)!} 0.25^2 (1-0.25)^{(7-2)}$$

$$P(2) = 31.15\%$$

The probability that a lot will be accepted is designated as **Pa**. The **Pa** can be accumulated in two conditions: 1) **Pa1**: the Probability that a lot will be accepted at first sampling, and 2) **Pa2**: the Probability for a lot to be accepted at second sampling.

Pa = the Probability that a lot will be accepted at first sampling

+ the Probability that a lot will be accepted at second sampling

$$Pa = Pa1 + Pa2$$

The Probability that a lot will be accepted at **first** sampling can be:

$$Pa1 = P(x1=0) + P(x1=1) + P(x1=2) + \dots P(x1=c1)$$

or,

$$Pa1 = P(x1 \leq c1)$$

To calculate the Probability that a lot will be accepted in the **second sampling**, two conditions should happen sequentially, including: 1) the product is neither accepted nor rejected in the first sampling, and 2) the products are accepted in the second sampling. By multiplying the probabilities of the two conditions, the probability for accepting the product in the second sampling can be represented as follows:

$$\begin{aligned} Pa2 = & P(x1 = c1+1) \bullet P(x2+x1 \leq c2) \\ & + P(x1 = c1+2) \bullet P(x2+x1 \leq c2) \\ & + P(x1 = c1+3) \bullet P(x2+x1 \leq c2) \\ & + P(x1 = c1+4) \bullet P(x2+x1 \leq c2) \\ & + P(x1 = c1+5) \bullet P(x2+x1 \leq c2) \\ & + P(x1 = c1+6) \bullet P(x2+x1 \leq c2) \\ & + \quad " \quad \bullet \quad " \\ & + \quad " \quad \bullet \quad " \\ & + P(x1 = r1-1) \bullet P(x2+x1 \leq c2) \end{aligned}$$

Simplify the equation:

$$\begin{aligned}
 Pa2 = & P(x1 = c1+1) \bullet P(x2 + c1 + 1 \leq c2) \\
 & + P(x1 = c1+2) \bullet P(x2 + c1 + 2 \leq c2) \\
 & + P(x1 = c1+3) \bullet P(x2 + c1 + 3 \leq c2) \\
 & + P(x1 = c1+4) \bullet P(x2 + c1 + 4 \leq c2) \\
 & + P(x1 = c1+5) \bullet P(x2 + c1 + 5 \leq c2) \\
 & + \quad " \quad \bullet \quad " \\
 & + \quad " \quad \bullet \quad " \\
 & + P(x1 = r1-1) \bullet P(x2 + r1 - 1 \leq c2)
 \end{aligned}$$

Then:

$$\begin{aligned}
 Pa2 = & P(x1 = c1+1) \bullet P(x2 \leq c2 - (c1 + 1)) \\
 & + P(x1 = c1+2) \bullet P(x2 \leq c2 - (c1 + 2)) \\
 & + P(x1 = c1+3) \bullet P(x2 \leq c2 - (c1 + 3)) \\
 & + P(x1 = c1+4) \bullet P(x2 \leq c2 - (c1 + 4)) \\
 & + P(x1 = c1+5) \bullet P(x2 \leq c2 - (c1 + 5)) \\
 & + \quad " \quad \bullet \quad " \\
 & + \quad " \quad \bullet \quad " \\
 & + P(x1 = r1-1) \bullet P(x2 \leq c2 - (r1 - 1)) \\
 Pa2 = & \sum_{i=c1+1}^{r1-1} P(x1 = i) \bullet P(x2 \leq (c2 - i))
 \end{aligned}$$

The accumulated probability that the products will be accepted is:

Pa = the Probability that a lot will be accepted at first sampling
- the Probability that a lot will be accepted at second sampling

$$\begin{aligned}
 Pa &= Pa1 + Pa2 \\
 &= P(x1 \leq c1) + \sum_{i=c1+1}^{r1-1} P(x1 = i) \bullet P(x2 \leq (c2 - i))
 \end{aligned}$$

Thus, Pa is a function of six parameters: $n1, n2, c1, r1, c2, pd$: $Pa = F(n1, n2, c1, r1, c2, pd)$.

Example:

Assume an acceptance system has the following parameters:

n1=10 : The required sample size in the first sampling.

n2=10 : The required sample size in the second sampling.

c1=1 : The first acceptable number.

r1=3 : The first rejectable number.

c2=4 : The second acceptable number.

x1 : the number of non-conforming items found in the first sampling.

x2 : the number of non-conforming items found in the second sampling.

All of the possible conditions that the lot will be accepted are:

x1 =0

x1 =1

x1 =2 and x2 =0

x1 =2 and x2 =1

x1 =2 and x2 =2

$$P_a = P(x_1 \leq 2) + \sum_{i=1+1}^{3-1} P(x_1 = i) \cdot P(x_2 \leq (c_2 - i))$$

$$= P(x_1 = 0)$$

$$+ P(x_1 = 1)$$

$$+ P(x_1 = 2) \cdot P(x_2 = 0)$$

$$+ P(x_1 = 2) \cdot P(x_2 = 1)$$

$$+ P(x_1 = 2) \cdot P(x_2 = 2)$$

where:

$$P(0) = \frac{10!}{(0!)(10-0)!} p d^0 (1-pd)^{(10-0)}$$

$$P(1) = \frac{10!}{(1!)(10-1)!} p d^1 (1-pd)^{(10-1)}$$

$$P(2) = \frac{10!}{(2!)(10-2)!} pd^2 (1-pd)^{(10-2)}$$

$$\begin{aligned} \mathbf{Pa} &= \mathbf{F(n1, n2, c1, r1, c2, pd)} \\ &= \mathbf{F(10, 10, 1, 3, 4, pd)} \end{aligned}$$

Or in detailed format:

$$\begin{aligned} \mathbf{Pa} &= \frac{10!}{(0!)(10-0)!} pd^0 (1-pd)^{(10-0)} \\ &+ \frac{10!}{(1!)(10-1)!} pd^1 (1-pd)^{(10-1)} \\ &+ \frac{10!}{(2!)(10-2)!} pd^2 (1-pd)^{(10-2)} \cdot \frac{10!}{(0!)(10-0)!} pd^0 (1-pd)^{(10-0)} \\ &+ \frac{10!}{(2!)(10-2)!} pd^2 (1-pd)^{(10-2)} \cdot \frac{10!}{(1!)(10-1)!} pd^1 (1-pd)^{(10-1)} \\ &+ \frac{10!}{(2!)(10-2)!} pd^2 (1-pd)^{(10-2)} \cdot \frac{10!}{(2!)(10-2)!} pd^2 (1-pd)^{(10-2)} \end{aligned}$$

When the variable **pd** changes, the **Pa** changes correspondingly. Assume **pd** is 5%.

By plugging the **pd**=5% into the above equation, **Pa** is:

$$\mathbf{Pa} = 98.7\%$$

Likewise, if **pd** increases to 20%, by plugging the **pd** into the above equation, the **Pa** decreases to 58%. The flow chart that summarizes this system's application is in Figure 3.2.

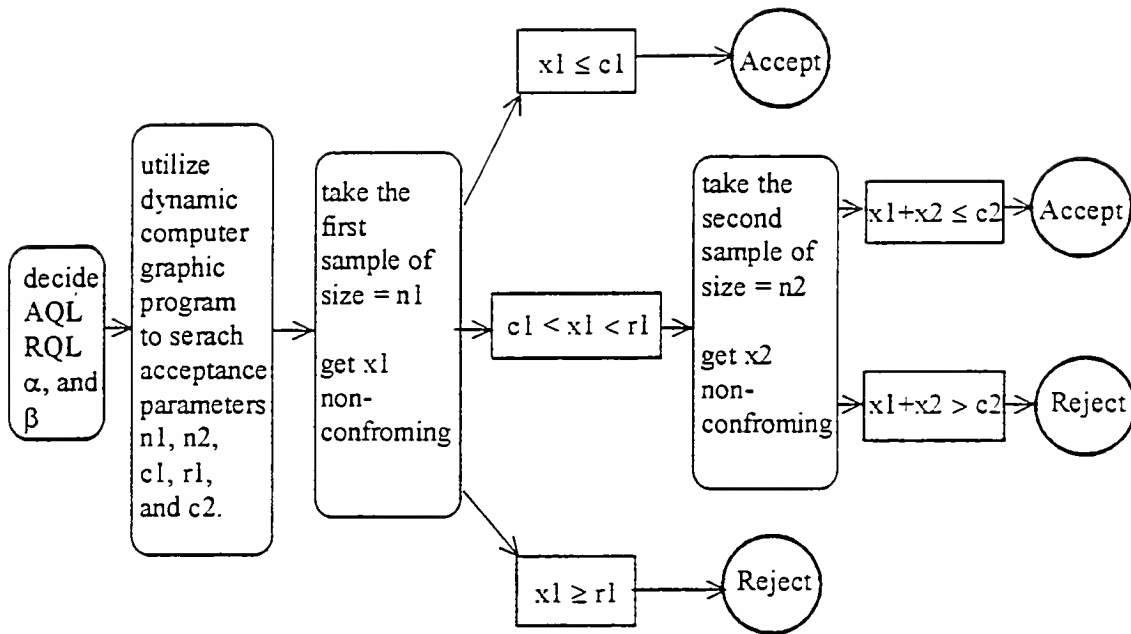


Figure 3.2 Flow Chart for Attribute Double Sampling Plan

3.5 Interactive Computer Graphic Program for Designing Sampling Systems

To determine the probability that a lot will be accepted, the function $P_a = F(n_1, n_2, c_1, r_1, c_2, p_d)$ is applied. The double sampling acceptance system is decided by five parameters: n_1 , n_2 , c_1 , c_2 , and r_1 . After the above five parameters are decided, the incoming product with a underlying p_d (percent of defect) will correspond to a certain P_a (probability of acceptance). Once the five parameters are decided, the double sampling system can be regarded as a black box. Any products with certain percents of defects go through the box and a decision to accept or reject is made. As mentioned before, a sampling system should be designed so as to manipulate the OC curve to match the desired AQL -- α risk, and RQL -- β risk. To design a reasonable double sampling, we need to properly choose the five parameters n_1 , n_2 , c_1 , c_2 , and r_1 , so that the OC curve can be controlled to match the desired AQL -- α risk, and RQL -- β risk.

However, because of the complexity of the equation and the many parameters, it is very difficult to choose the five parameters for designing a desired double sampling. No

monograph or table is currently available to assist in designing a double sampling system. To solve this dilemma, in this research, an interactive computer graphic program is developed to assist the design of the ADSS.

The following equation presents the probability of acceptance (**Pa**) for the product with an underlying percentage of defect (**pd**):

$$Pa = P(x_1 \leq c_1) + \sum_{i=c_1+1}^{r_1-1} P(x_1 = i) \bullet P(x_2 \leq (c_2 - i))$$

Given that the five parameters n_1 , n_2 , c_1 , c_2 , and r_1 are decided, by plugging the pd into the equation, the corresponding Pa can be easily obtained. If we plug in a series of pd with very tiny intervals, from 0% to 100%, and calculate the resulting **Pa**, we can plot an OC curve representing the designed double sampling system (Figure 3.1). But how can we properly choose the five parameters n_1 , n_2 , c_1 , c_2 , and r_1 so that they will produce a desired OC curve? Unfortunately, the above equation is so complex that it is impossible to solve the five parameters n_1 , n_2 , c_1 , c_2 , and r_1 , by giving a pair of **Pa** and **pd** (a set of AQL -- α risk, and RQL -- β risk). Also, because the five parameters are all positive integers instead of continuous variables, the equation cannot be solved in a close form solution.

To solve the above problem, a computer graphic program was developed. It allows the users to interactively design the double sampling system. Before using this program, the users may have a set of AQL -- α risk, and RQL -- β risk requirements in their minds. Using this program, users simply assign the five parameters n_1 , n_2 , c_1 , c_2 , and r_1 , and the resulting OC curve will be shown on the screen. Adjusting the five parameters will change the OC curves correspondingly. The users interactively change the five parameters until they find a reasonable OC curve. In the program, the producer's (α) and owner's (β) risks are pre-defined in the 5% level. As a result, the AQL and RQL are the values that OC curves pass the 95% and 5% levels in the **Pa** axis. By checking the AQL and RQL, users

can judge whether a desired double sampling system has been obtained. The following example explains the operation of the program.

Example for Using the Interactive Computer Graphic Program

Assume that the highway agency decides to design a double sampling system complying with the following conditions:

- 1) If the product is 5% non-conforming (defect), the highway agency regards the product as definitely acceptable.

That is $AQL=5\%$.

- 2) If the product is 35% non-conforming (defect), the highway agency regards the product as definitely rejectable.

That is $RQL=35\%$.

- 3) The Producer's and Owner's risk are both controlled in 5% levels.

The First Trial

The n_1 and n_2 are first set to be 5. The c_1 , r_1 , and c_2 are set to be 0, 2, and 1 respectively. Under pre-defined 5% risk levels, from the output screen of the interactive computer graphic program, the resulting AQL and RQL are 5% and 46% respectively (please see Figure 3.3). At the first trial, the resulting RQL 46% is too loose. A larger sample size will be tried in the next test.

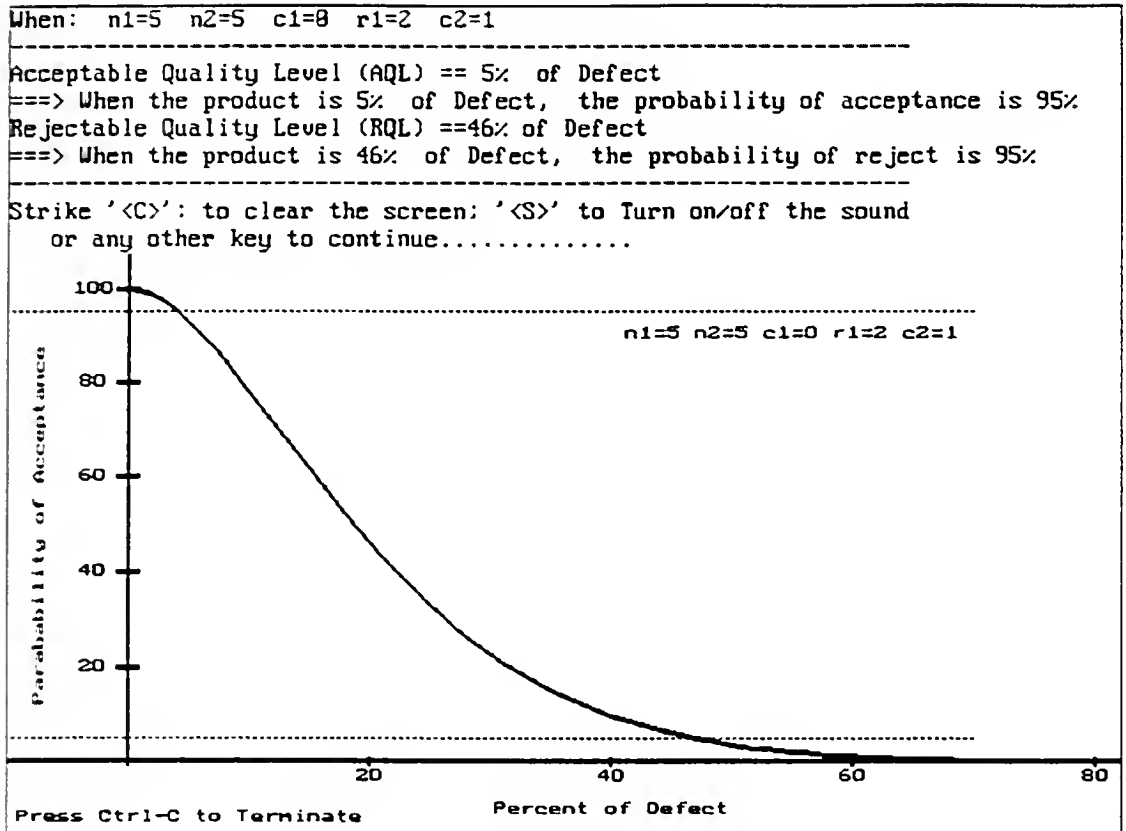


Figure 3.3 Direct Screen Output in the First Trial

The Second Trial

Based on the previous trial, the $n1$ and $n2$ are increased to 10. The $c1$, $r1$, and $c2$ are set to be 0, 2, and 1 respectively. The resulting AQL and RQL become 2% and 27% respectively (please see Figure 3.4). At this trial, both AQL and RQL are too strict. Larger $c1$, $c2$, $r1$ will be tried in the next test.

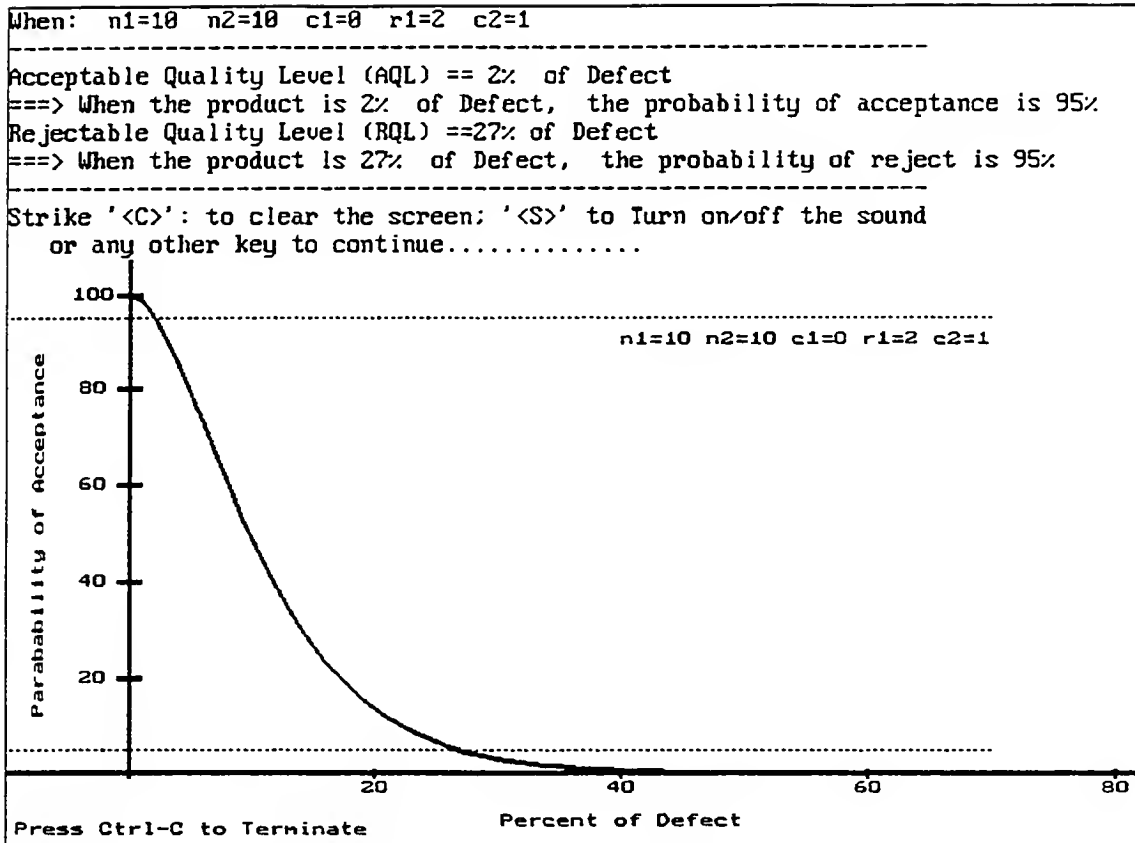


Figure 3.4 Direct Screen Output in the Second Trial

The Third Trial

The n_1 and n_2 are kept at 10. The c_1 , r_1 , and c_2 are set to be 1, 3, and 2 respectively. The resulting AQL and RQL become 6% and 39% respectively (please see Figure 5). The original expected conditions are AQL=5% and RQL=35%. The resulting AQL and RQL are quite close to the expected design. Therefore, the attribute double sampling system with the parameters: $n_1=10$, $n_2=10$, $c_1=1$, $r_1=3$, $c_2=2$ is accepted. If a more accurate match between the expected conditions and the results is required, then more trials should be done to obtain a closer solution.

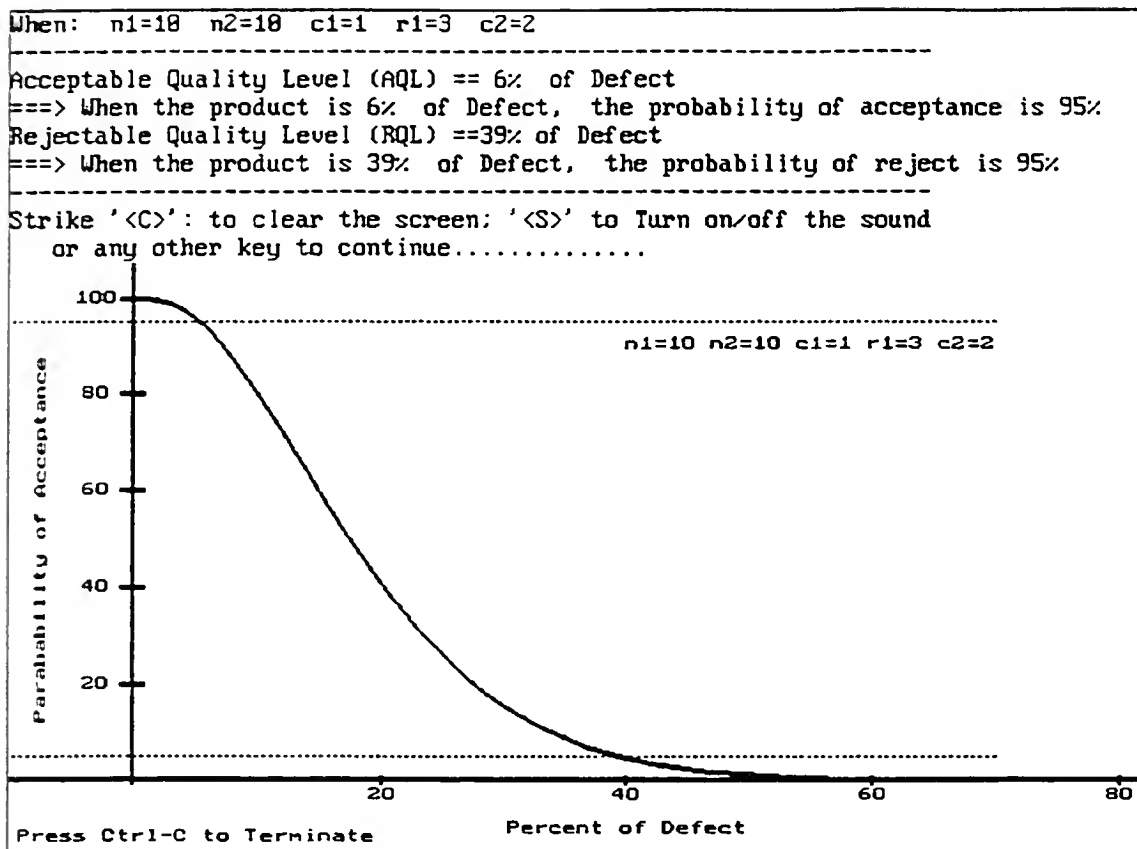


Figure 3.5 Direct Screen Output in the Third Trial

Assume that the highway agency would like to design an attribute double sampling system having the conditions:

$$AQL = 5\% = 0.05 \quad \text{and} \quad \alpha = 5\%$$

$$RQL = 35\% = 0.35 \quad \text{and} \quad \beta = 5\%.$$

After designing the double sampling system in the interactive computer graphic program, the highway agency chooses a set of parameters:

$$n1 = n2 = 10$$

$$c1 = 1 ; r1 = 3$$

$$c2 = 2$$

which closely match the pre-set criteria. This set of parameters controls the following conditions:

$$AQL = 6\% = 0.06 \quad \alpha = 5\%$$

$$RQL = 39\% = 0.39 \quad \beta = 5\%$$

For example, with the above information, the highway agency can specify the acceptance system for DFT in primer (or top-coating) as follows:

Example Specification:

The lower limit (L) for the dry film thicknesses of primer is 2.5 mils. In each lot, the first inspection sample of size 10 should be taken by inspectors and the number of non-conforming items found is designated as x_1 .

if $x_1 \leq c_1=1$ then accept the lot;

if $x_1 \geq r_1=3$ then reject the lot;

if $c_1 < x_1 < r_1$, then a second sample of size 10 should be taken.

Non-conforming items found in the second sampling are designated as x_2 .

So x_1+x_2 non-conformings in the two samples of size n_1+n_2 are found

if $x_2+x_1 \leq c_2=2$ then accept the lot

if $x_2+x_1 > c_2=2$ then reject the lot

The Risk Control Points are:

$$AQL = 6\% = 0.06 \quad \text{at } \alpha = 5\%$$

$$RQL = 39\% = 0.39 \quad \text{at } \beta = 5\%$$

3.6 Rules for Designing the Attribute Double Sampling System

When using the above computer graphic program, it is not recommended that the users just randomly assign the five parameters: n_1 , n_2 , c_1 , c_2 , and r_1 . The users may not be lucky enough to obtain the desired system in a few trials. However, there are some rules that can facilitate the design work. The rules for designing the ADSS are as below; these are also summarized in Table 1.

- Rule 1.** When the n_1 , and n_2 are increased, the slope of the OC will become steeper; the acceptance sampling system has more power in distinguishing good and poor quality. In other words, the AQL and RQL will both switch toward the left hand side (decrease). Also, because the OC curve becomes steeper, the interval between AQL and RQL will decrease, and vice versa.
- Rule 2.** When the c_1 , c_2 , or r_1 are increased, the acceptance sampling system becomes looser. Both the AQL and RQL will often increase, and vice versa
- Rule 3.** When all five parameters: n_1 , n_2 , c_1 , c_2 , and r_1 increase simultaneously and proportionally, the slope of the OC will become steeper. In this situation, the AQL will increase, but the RQL will decrease. The interval between AQL and RQL will decrease, and vice versa.

Table 3.1 Rules for Designing Attribute Double Sampling System

n1, n2	c1, r1, c2	Effect
increase	keep the same	sharper slope of OC curve AQL and RQL decrease interval between AQL and RQL decrease
decrease	keep the same	flatter slope of OC curve AQL and RQL increase interval between AQL and RQL increase
increase proportionally	increase proportionally	sharper slope of OC curve AQL increase; RQL decrease interval between AQL and RQL decreased
keep the same	increase	looser acceptance plan AQL and RQL increase
keep the same	decrease	stricter acceptance plan AQL and RQL decrease

Chapter 4 Trial of Designed Inspection Forms

4.1 Background

To increase the feasibility of the designed inspection system, the researchers continuously collect the feedback about the use of the new inspection system. By visiting job sites and conducting four interviews to two inspection teams, the processes of using the inspection forms were observed. Valuable knowledge and information are obtained from inspectors and resulted in a modified inspection contents and forms. The revised inspection forms are presented in the second part of Appendix D.

4.2 Results and Feedback from Field Trails

To continuously collect feedback about the new inspection system, the researcher visited job sites and conducted four interviews of two inspection teams. The processes for using the inspection forms were also observed. Valuable knowledge and information were obtained from inspectors and resulted in modified inspection contents and forms. The three types of questions asked of the inspectors were:

- 1). How do you like the paper forms provided?
- 2). What do you think about the designed inspection procedures?
- 3). What changes would you like to suggest to improve the inspection forms?

The results from the trial of the new inspection system are summarized as follows:

- The INDOT's inspectors like the inspection forms. They provide step-by-step inspection guides and supply a place to keep the results of inspections. Before the inspection forms were developed, inspectors simply recorded measurements on their

personal field books. However, the designed inspection forms are much more complete and convincing.

- The size of 8.5" x 11" inspection forms was too large when the inspectors accessed bridge structures. Currently, inspectors record data in smaller informal field books that are more easily kept inside their pockets. Smaller inspection forms (5.5" x 8" required by the first team; 5.5" x 4" by the second team) were requested.
- The inspection forms require measurements to be taken on the bottoms of top flanges. These areas take more time to measure because of the vibration caused by heavy vehicles.
- SSPC I-89 surface cleanliness standard does not work well when bridge beams are steel-shot blasted. The appearance of blasted surface changes between sandblasting and steel-shot blasting. One team has used a X3 power lens to check the cleanliness of the blasted surface. The cleanliness of air is currently checked by coffee filters.
- The summary table on Form 3 is considered to be repetitive and redundant. The inspectors suggested that it be deleted.
- The inspection system was not designed for the use of spot painting. Inspectors have no way of knowing where the old paint is, and where the new is. In spot painting, organic paint is used because it adheres better to the old paint. The organic can adhere to the inorganic; the inorganic cannot adhere to the inorganic. However, the solvent in the new organic paint will penetrate into the old primer and make the old inorganic paint peel. The first team disagreed with spot painting.

- The question about when to measure the dry film thickness was raised. Several types of paints won't cure until several hours or days of application. For example, the MEK (a solvent) takes around 5 days to cure.
- For environmental concerns, the INDOT requires contractors to apply steel shot blasting instead of conventional sand blasting. The reason is that the steel shots can be recycled and the contaminated dusts can be separated with recycling devices. However, the cost for blasting a bridge increases from \$1.75/sq-foot to \$4.0/sq-foot. The environmental problems have become crucial. Additional items for checking environment controls, such as the treatment of removed lead paint should be added to the inspection forms.
- The INDOT's field engineers have their own engineer kits (Tool Box) containing the required equipment for inspection. There is no equipment support problem.
- The workload for using the inspection form is acceptable. Inspectors have been performing similar work without official inspection forms. Now the inspection forms can provide inspectors with clear guides and places to keep the measured results.
- Inspectors' short courses were helpful. One team hoped that they could have another chance to attend it again, like the one held in the spring of 1990. The first team said, "Training short courses definitely strengthen inspectors' capability." The second team also attended the same inspection training course held in the spring of 1990. However, opposite opinions came from the second team. The second team said "this program is inefficient and useless." The training program only taught inspectors the theory of corrosion, how paint materials can pass the state laboratory test, how to wear the mask, and so forth. These teaching contents are not major concerns. On the contrary,

the training course should, but did not teach inspectors 1) **how to make the decision to reject a defective job**, 2) **how to ask contractors to fix defects**, and 3) **how to process the inspection paper work**. They need a more practical inspection knowledge instead of background of corrosion theories. The opinions were sincerely considered when Purdue researchers designed the training session.

- The second team pointed out that the painters did not speak English. The inspectors had difficulties communicating with the painters.
- It will be a problem transporting computers up to the bridge structures. The computers were difficult to handle and apt to be damaged. A lap-top computer operated inside the car is acceptable. Inspectors can record the results on paper forms and key them into the computer after returning to the car. One day's data are not much. The problem is the data belonging to several projects in several months. Keeping the complete files of data in paper form is troublesome. Computers can help with some database systems. Also, the FAX modem will be useful in communicating between sites and offices.
- The space for recording beam location needs to be enlarged in the inspection forms.
- For the second team, the contractor did not notify the inspectors before they worked. It happened that the contractor urgently put the top coating over the primer without allowing the inspectors to check whether the primer had been properly applied. Therefore, defects such as contaminated surface, bubbling, and mud-cracking of the primer may be hidden. Communication between inspectors and contractors needs serious improvement. Personal pagers could be helpful. The requirement that "contractors must notify inspectors before work" should be clearly specified. Several hold points should be strictly enforced. The following recommendation is made by the

second team: The state should specify that contractors must get signatures at certain hold points, or no payment will be made. There is a similar document called "form 460" that requires the signatures of both contractors and inspectors to process the payment.

- The second team pointed out that the serious problem is not on the inspection forms, but on how to ask the contractors to fix the defective areas. For example, problems of bubbling happened seriously in one project. According to the state specification, the bubbling area should be corrected. Everybody knows that. However, there is no clear guide of how the contractor should fix the problems. Currently, when the bubbling defects were found, the contractors just simply scraped away the bubbling spots and put additional top-coat over the small pin holes. One member of the second team voiced his disagreement with this repair procedure and claimed that he has no specifications as a support to stop the contractors. The following two questions must be answered in the state specification. First, how many bubbles should be counted to fail the inspection? Second, when bubbles are found, how should the contractors fix them, by scraper, or sand-blasting? The specification missed several-real world problems.

Chapter 5 Training Session

5.1 Needs of Training Session

Under the Joint Highway Research Project HPR-2029-89-27, statistical quality acceptance systems have been developed. Nevertheless, the benefits from the research results cannot be fully realized until the systems are incorporated into inspectors' daily practices. To adopt the new systems, inspectors need to be trained.

5.2 Inspection Training Program

The INDOT central office and Purdue University conducted a steel bridge painting inspection training program to introduce the designed QA inspection system. The training program was held in the Indiana Government Central North Building at the end of May. Ten bridge painting inspectors from six different districts attended this training program.

In response to the feedback obtained from interviews, it is apparent that inspectors are not concerned about the underlying statistical theory of the acceptance system. On the other hand, what they need to know is a set of clear procedures for doing daily quality control on job sites. Therefore, in the training program, the content of statistical background was reduced to the minimum. In short, the training course was designed to teach inspectors:

- (1) how to take samples,**
- (2) how to make decisions to accept a quality job or reject a defective job, and**
- (3) how to process the inspection paper work on the provided inspection forms.**

In the training course, a series of simple but comprehensive examples was used to describe the double sampling system. Meanwhile, the inspection forms for four stages were introduced to the inspectors, including:

- (1) pre-inspection,
- (2) surface preparation,
- (3) priming, and
- (4) Top-coating stages.

In general, the inspectors' response to this training program was positive.

At the end of the training course, the INDOT central office encouraged the inspectors to try the new quality assurance system and inspection forms on job sites. However, the decision to reject or accept was still based on the original system, which depends heavily on inspectors' personal judgment. The inspection results obtained from the new system can be a valuable reference. More feedback is needed before the system can be fully adapted. Also, The computerized QA inspection system was presented. Then the QA computer software was distributed to both office and job sites. The process of using the QA program was observed. Valuable advice was obtained from both inspectors and the central office.

After the training session, many inspectors expressed their willingness to use the inspection forms right away. The training menu and inspection forms used in the training program can be found in Appendix D.

Chapter 6 Development of the Pen-Computer System

6.1 The Needs for Computerization

Maintaining construction quality is field engineers' major responsibility. However, processing inspection data at construction sites takes field engineers a considerable amount of time. First, they need to record many measurement on inspection forms. The daily inspection data can be tens of pages. After the data are recorded on paper format, they are brought back to the offices. If computers are utilized, these data need to be manually typed into computers for further processing. In this case, the double-data-entry requires additional work and may cause errors. On the other hand, if computers are not utilized, the paper inspection forms will be piled around offices and the among of the paper forms will quickly become out of control. Many efforts have been made in collecting and processing inspection data of highway constructions. The growing construction data are overwhelming field engineers.

Due to the lack of an efficient data process, the requirement for maintaining inspection data is usually reduced to its minimum. In conventional steel bridge painting, the inspectors do not record and process inspection data. After the project is finished, the information associated with the products is gone. Therefore, many inspection decisions are made without sufficient supporting data.

To solve the above problems, inspection procedures on construction sites need to be computerized. The pen-based computer is proposed to break the barriers in transmitting computer technologies onto construction sites. Thus, a **PE**n-based computer system for **P**ainted **S**teel bridge **I**nspection (**PEPSI**) was developed. Currently, a menu-driven interface for data capture and process has been built inside the **PEPSI** system. Since the inspection forms have been computerized and the field engineers can directly input measured data into the computers, statistical data processing will be done with the

power of computers. The acceptance or rejection decision is automatically made right after the finish of data input. This not only reduces the necessity of inspectors having statistical background, but also eliminates tedious paper work.

6.2 Review of Pen-Computer Technology

The pen-based computer is one of the most recent developments in computer technology (Barr, Christopher, 1992; Baran, Nicholas, 1992b). A pen-computer uses a pen as the input device for a portable computer. It features a handwriting recognition system that allows users to write directly on the screen and then convert the input to characters, just as if they had come from a keyboard (Miastkowski, Stan, 1992). The handwriting recognition technologies applied included neural networks, probabilistic Markov modeling, fuzzy logic, dynamic programming and clustering algorithms (Quain R. John, 1993).

Currently, there are two types of Digitizer technologies used by the pen-based computers including Restrictive and Electro-Magnetic (EM) Digitizers.

- A Restrictive digitizer is overlaid onto the surface of Liquid Crystal Display (LCD). The pen mark directly contacts the LCD's surface. A conductive coating on the surface sends x and y pen coordinates by determining the voltage emitted by the screen.
- An Electro-Magnetic (EM) digitizer is embedded beneath the LCD. The EM digitizer has certain advantages over the resistive digitizer. For instance, some restrictive units lower the light transmitted by the LCD due to an extra coating of wires on the screen (Barr, Christopher, 1992).

6.3 Advantages of Using Pen-Based Computers

Pen computers are proposed for people who are away from their offices but still want to utilize the power of computers. Unlike laptop or note-book computers, pen-based

computers can be used while standing or walking. Therefore, they are good for highway engineers who work on construction sites. It is inconvenient to pull out a laptop computer and start typing in the middle of working. However writing on the screen of a pen computer is no more unwieldy than taking notes on a clipboard (Miastkowski, Stan, 1992).

Pen computers provide another advantage in that they can be used to keep handwriting records for legal purposes. For example, United Parcel Service (UPS) has replaced its drivers' traditional clipboards with electronic versions -- a form of pen computer. Package recipients no longer sign paper forms; instead, they sign their name directly on the drivers' computers. The signature image is stored together with the delivery time and date. For public highway construction projects, numerous signatures are necessary for processing paperwork. The benefit can be even more tremendous if the signatures and relative documents can be maintained in electronic format that can be easily processed and transferred between offices.

In another area, pen computing in the CAD market seems to be a natural evolution. The applicants can directly sketch markup in the field on their pen computers, just drawing an "X" over the defective beams that need repairing. Engineers checking field installations could carry pen computers on their arms rather than rolls of detailed drawings.

6.4 Hardware

With the explosion of computer technologies over the past one year, a tremendous number of pen-computers with more powerful functions have become available. To choose the pen-computer that is most suitable for the data collection for INDOT's steel bridge painting inspection, the state-of-art pen computers were reviewed.

6.4.1 Evaluation of Different Pen-Computers

In evaluating pen-computers, "portability" is one of the most important criteria. In other words, the candidate pen-computers should be both small-sized and light weight enough to allow INDOT's inspectors to carry them easily to job sites. Under the above criteria, four pen computers are initially selected. They are 1) Dauphin DTR-1, 2) Fujitsu Poqetpad Plus, 3) AT&T EO System, and 4) Grid PalmPad. Appendix A contains more detailed descriptions of the above pen-computers. Their features in brief are as follows:

- **Dauphin DTR-1**

The 2.5 pound Dauphin DTR-1 is only 1.25 by 9 by 5 inches, but is a high speed computer. Using a Cyrix 25 MHz 486SLC processor, it is a best bet for multi-purpose computing. Coming with 4MB of RAM and 20MB of hard disk, it runs with MS-DOS, Microsoft Windows 3.1., and Windows for Pen.

- **Fujitsu Poqetpad Plus**

The Fujitsu PoqetPad plus is a lightweight (1.6 pounds) hand-held computer. It provides up to 12 hours of continuous computing time. The built-in infrared link transfers data without a cable connection.

- **AT&T EO 440**

The AT&T EO 440 is another powerful pen-based communicator for office users. The AT&T EO 440 system is a good device for cooperating with the telecommunication devices. It is designed for use by workers who want Fax, e-mail and voice contact while on the road or at construction sites. Compared with other pen-computers, EO440 is large (10.8 by 7.1 by 0.9 inches, and weighting 2.2 pounds). Nevertheless it is a handy communication device.

- **GRID PalmPad**

The PalmPad has the dimension of 1.9 x 9 x 6.2 inches and weight 2.9 pounds. It is a rugged, lightweight, and small pen computer. The PalmPad is designed for rough use and aimed primarily at field users who abuse machines or who work in harsh environments. It is ruggedly built and has an exterior that is entirely plastic. The rubber seals around the screen and control buttons make the product safer for drops and spills. Because it is small, it allows the inspectors to attach the wrist or belt.

The CPU used in GRID PalmPad is slow and only good for simple application. It comes with a 2MB RAM and has a PCMCIA slot with a built-in IDE controller that can hold sundisk flash-memory cards up to 30MB. Unfortunately, the PCMCIA slot does not have an ejection mechanism. The PCMCIA card must have a pull tab before inserted. To link users to the outside world, PalmPad features an optional communication model. Besides cable connection, choosing an integrated 902-928 MHz Spread Spectrum Radio for wireless communication allows this device can communicate with other host computers. In summary, the PalmPad is good for use as a device for data-collection tasks in harsh environments.

6.4.2 Selection of Pen-Computers

The pen-computers introduced in the previous section have their own characteristics. To choose one suitable computer from them, two criteria need to be considered: 1). the features in bridge construction sites, and 2) the data needed in painting inspection.

After we evaluated the above criteria, the Grid PalmPad was suggested as the preferable pen-computer. The reasons are as follows:

- **Construction sites have severe environments.**

A construction site for steel bridge painting may be over a river or a highway. Rain and water may spill on the computers. A complete protection of the computers is absolutely necessary. For this reason, the Dauphin DTR-1 is not the choice, because the Dauphin DTR-1 is designed with many openings for cooling down its high speed CPU. This can be a dead point for the equipment. Also, its high speed CPU consumes the power much faster, and it may use up the power before the inspectors get a chance to recharge its battery.

- **A large amount of data is needed in the painting inspection processes.**

A large amount of data is required in painting inspection: usually more than 20 pages of data for one painted bridge. For this reason, it is better to choose the pen-computer which can contain more information on one single screen page. For this reason, the Fujitsu PoqetPad was rejected because it only has a 600 x 200 resolution screen, which is less than the half size of the general PC monitor of 600 x 480 resolution. Due to this limitation, the inspection program would have to be designed in a rather small screen page. The required pages increase up to 40 pages or more. As a result, inspectors would need to flip around the screen pages too much.

- **Other Advantages of Using Grid PalmPad**

Being classified as a palm-sized pen computer, PalmPad is light for long periods of use. It is cushioned by a rubberized plastic casing, which resists shock of 273G at 2 mini seconds. This feature makes the PalmPad the best bet in harsh construction sites. The PalmPad has a screen of 640 x 400 resolution, which is very close to the general PC used every day. Therefore, the pen-computer program can be designed in two parallel versions that are exactly the same including: one run under pen-

computers and the other under PCs. Also, its high resolution screen allows the program to use printing screen function. On the other hand, Fujitsu Poqetpad only features a 600 x 200 resolution screen, which will make the printing screen function very limited, because only half a side of the paper is used.

6.5 Software

Four major operation systems are currently available in the pen-based computer market. They are **Window for Pen** from Microsoft, **Penpoint** from GO Corporation, **PenRight** from GRiD system corporation, and **PenDOS** from Communication Intelligence Corporation (O'Connor, Thom, 1992).

Grid's PenRight system was chosen to develop the inspection form-oriented applications. PenRight is a software platform for executing mission-specific applications on top of MS-DOS. PenRight has performed successfully in several vertical applications in which the computer performs one specific type of task for the users (Intorcio, John, 1992). Under the PenRight system, the data entry system was developed under the package "**PenPAL**" from Pen Pal Association. For detailed functions of this system, please refer to its user manual.

6.6 Development of the Pen-Computer System

The inspection procedures for field bridge painting were divided into four stages including: (1) pre-inspection, (2) surface preparation inspection, (3) primer inspection, and (4) top-coat inspection. In these four stages, inspectors need to record surface cleanliness, coat thickness, ambient conditions, material used, and many more data. Currently, the whole inspection procedure is incorporated into a series of inspection forms. Inspecting a bridge painting usually needs tens of pages of paper forms.

The PEn-based computer system for Painted Steel bridge Inspection (PEPSI) has been developed to provide an electronic version of inspection forms. It is a data base established under a pen-based computer environment. This database features a user-friendly interface with which inspectors can easily enter the measured data on construction sites.

6.6.1 PEPSI Overview

The PEPSI represents a PEn-based computer system for Painted Steel bridge Inspection. In this system, contractor and structure numbers are used as key fields in the database. By specifying the contractor and structure numbers, inspectors can create and assess the data belonging to different projects. There are a total of 20 pages of forms in the system. The PEPSI system features a user-friendly interface, allowing inspectors to directly input measured data by using a pen. Meanwhile, the acceptance or rejection decisions will automatically be made when data input is completed. This approach not only reduces the necessity of inspectors' statistical background, but also eliminates tedious paperwork. In addition, after the data are entered, the data can be efficiently transferred to a host computer in the central office to establish a global database.

Hardware:

The state-of-art pen computers were reviewed to select a suitable pen-computer. "Portability" is one of the most important criteria in selecting the pen-computers. The candidate pen-computers must be both small-sized and light-weight. Finally, the Grid PalmPad was considered preferable for inspection applications. As mentioned before, the Grid PalmPad features some basic water-proof capability. Being classified as a palm-sized pen computer, the PalmPad has the dimensions of 1.9 x 9 x 6.2 inches. Weighting 2.9 pounds, it is light enough for long periods of use. Because it is cushioned by a rubberized plastic casing, which resists shock of 273G at 2 ms, it is ideal candidate in harsh bridge

construction sites. The PalmPad features a screen of 640 x 400 resolution, which is close to the general PC used every day. Therefore, the PEPSI database has been designed in two parallel versions: one for the pen-computers and the other for the PCs.

Software

PenRight was chosen because it is compatible with the Grid's proprietary hardware. It is a software platform for executing mission-specific applications on top of MS-DOS. The pen-based data entry system was developed under the package "PENPAL" from Pen Pal Association.

6.6.2 Methods of Data Entry

In the PEPSI system, four methods have been designed for data entry including:

- 1) Hand Writing Recognition,
- 2) Simulated Keyboard,
- 3) Pop Up List, and
- 4) Control Buttons.

- **Hand Writing Recognition**



For hand writing recognition, simply place the pen tip on the field, and it will zoom up a large field to facilitate users' hand writing input. Figure 6.1 shows the zoomed up field. The user can directly write alphabets and digits on the field. Then the system will recognize the hand writings and convert them into the ASCII texts. After users finish hand writing entries, they touch the "OK" button on the left bottom of the zoomed field to accept the input.

Please place your pen on the field.

Enter the Contract #

Contract Number Format Coding: A#####
A:Alphabet #:Digit

M	3	7			
---	---	---	--	--	--

OK  CANCEL  ← → ↑ ↓


Page  Next Page

Figure 6.1 The screen of hand writing recognition

- **Simulated Keyboard**

In some cases, the users' handwriting cannot be correctly recognized by the system. By touching a keyboard-like symbol on the bottom of the zoomed field in Figure 6.1, users obtain a simulated keyboard shown in Figure 6.2. Then users can place the pen tip on the simulated keyboard as if they are using a finger to type the desired data into the field.

- **Pop Up List**


To write on the data field or to type on the simulated key board is still as tedious as writing on a paper form. However, for many types of data, the possible data entries are limited and can be pre-defined. For example, the bridges in the State of Indiana are managed by seven district agencies. Therefore, the PEPSI system has a pop-up list to contain those seven possible choices. When the users touch the field with the pen tip, a list


is popped up as shown in Figure 6.3. The list includes all of the possible choices. After placing the pen tip on the desired choice, the chosen one will be inserted into the data field.

Please place your pen on the field.

Enter the Contract #

Contract Number Format Coding: A#####
A:Alphabet #:Digit




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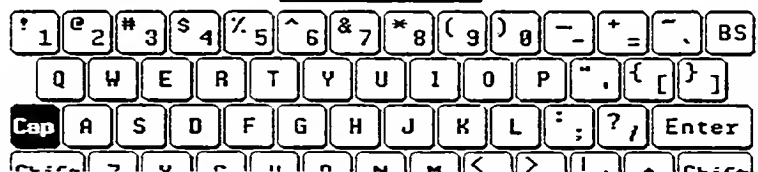

Pag


Figure 6.2 Simulated Keyboard for Data Input

Inspector's Name

Contractor's Name

District


Previous Page

- Crawfordsville**
- Fort Wayne
- Greenfield
- LaPorte
- Seymour
- Vincennes
- Toll Road




Figure 6.3 Pop Up List for Data Input

- **Control Buttons**

Many simple inspection processes can also be presented by yes/no questions. This type of data entry can be presented by a set of radio buttons of "yes" or "no." Figure 6.4 shows many yes/no questions. Users can simply place the pen tip on the radio buttons to toggle their answers. Also, to control the functions and to navigate among the data base, control buttons are designed. These control buttons include: *Exit*, *Go To Previous Page*, *Go To Next Page*, *Erase*, *Save* and so forth. Users can simply place the pen tip on the button to trigger the desired functions.


Primer Inspection		Date: <u> / / </u> mm/dd/yy	Go to Main Menu
Paint Manufacture's Name <u>J.o.n.h.</u>			
Paint Material Approved <input checked="" type="radio"/> Yes <input type="radio"/> No			
Batch # of Paint <u> </u>		Color <u> </u>	
Is paint Well Mixed? <input checked="" type="radio"/> Yes <input type="radio"/> No			
Thinning Approved ? <input type="radio"/> Yes <input checked="" type="radio"/> No			
Cleanliness of Surface before Painting?		<input type="radio"/> Yes <input type="radio"/> No	
Is DFT Gage Calibrated ?		<input type="radio"/> Yes <input checked="" type="radio"/> No	
Air-Less Spray?.....		<input type="radio"/> Yes <input type="radio"/> No	
If No, Check the Air-Cleanliness?		<input checked="" type="radio"/> Yes <input type="radio"/> No	
Do the Contractors Cooperate with INDOT by Helping Inpsectors Access Birdge? <input type="radio"/> Yes <input type="radio"/> No			
	Signature <u>Machine</u>		Goto Next
Previous Page	Erase		

Figure 6.4 Control Buttons for Data Input and Form Navigation

6.6.3 PEPSI Design Objectives and Its Functions

Many objectives and functions must be fulfilled to make the PEPSI a superior version to the conventional paper inspection form. The objective of the designs and its functions are summarized as followed.

1. Offer Better Protection from Non-Authorized Data Input

When a conventional paper form is used, the person recording the data can be recognized by the penmanship on the paper form. Therefore, the non-authorized person intending to fake the data can be detected. However, in pen-based computers, the user's handwriting is recognized and converted to a series of ASCII character format, and the original hand writing is gone. As a result, there is no way to distinguish who input the data. For this reason, the electronic forms require a better protection from non-authorized data input. To do so, the PEPSI system has been designed so that the inspectors must enter a valid password to enter the program. Furthermore, to better assure the reliability of the data, inspectors' signatures are requested. The middle bottom of Figure 6.4 shows the signature for validating the primer inspection data. Therefore, the recorded inspection forms can be regarded as legal documents.

2. Detect Error Data Entries.

Many erroneous data entries may happen during inspection. Therefore, an error-checking mechanism has been designed in the PEPSI system. For instance, the format of contract number should begin with an alphabetic followed by 5 digits. If a contract number with an incorrect format is entered, the system will detect this error and present a warning screen, make a beeping sound, and ask for a new input. In the course of inspection, many critical data must be fulfilled before further inspection can be taken. For example, the required surface cleanliness should be specified before the inspection of surface

preparation. The PEPSI has been designed to force the users to finish those critical data entries before they can exit one form and enter another. All of these designs serve as essential error-checking mechanisms for the inspectors.

3. Provide Instruction for Data Entry

Instructions should be provided to assist data input. The PEPSI has included many instructions on the screen to help users operate the program. For example, notes such as "Please place your pen on the field" in Figure 6.1 give the end-users a clear guide about what to do. In addition, the PEPSI features the intelligence to automatically guide the user to take proper actions. For example, the attribute double sampling has been adopted as the decision-making mechanism in the PEPSI system. If the measured data lead to the decision of taking a second sampling, then the PEPSI will automatically remind the users to take the second sampling by switching to the pages of the second sampling. Furthermore, several types of beep-sounds and rhythms are utilized to remind the users to take certain actions. For example, after the data are input, the acceptance or rejection decision is made automatically. If the product should be accepted, a smooth and short rhythm is produced. On the contrary, if the product should be rejected, an unpleasant and long rhythm is presented to remind the inspector to reject the products. All these designs are aimed to provide the users with audio and video instruction.

3. Remain Compatible with the Down Stream Application

The PEPSI system is designed for integrating with a database in the highway agency's central office. To do so, the "dbf" file format is used to store the measured data. The "dbf" format has become a standard data file that is accepted by most commercial database and spreadsheet packages. Additionally, the image files for drawings and signatures are stored in the format of pcx files. Once these data are recorded, the data files can be efficiently transferred to other computers. Its final goal is to integrate the field

inspection data to establish a database that the highway agencies to retrieve and analyze the construction quality.

4. Provide Drawing Capability

A picture may save thousands of words. Therefore, the PEPSI has been designed to provide a drawing capability. A drawing board in the PEPSI helps inspectors describe information that cannot be easily described in words. The drawing board provides three basic functions: free hand drawing, eraser, and stamp. For example, the basic configuration of the bridge can be sketched on the drawing board. Figure 6.5 shows that the defective area requiring rework is marked on the bridge drawing.

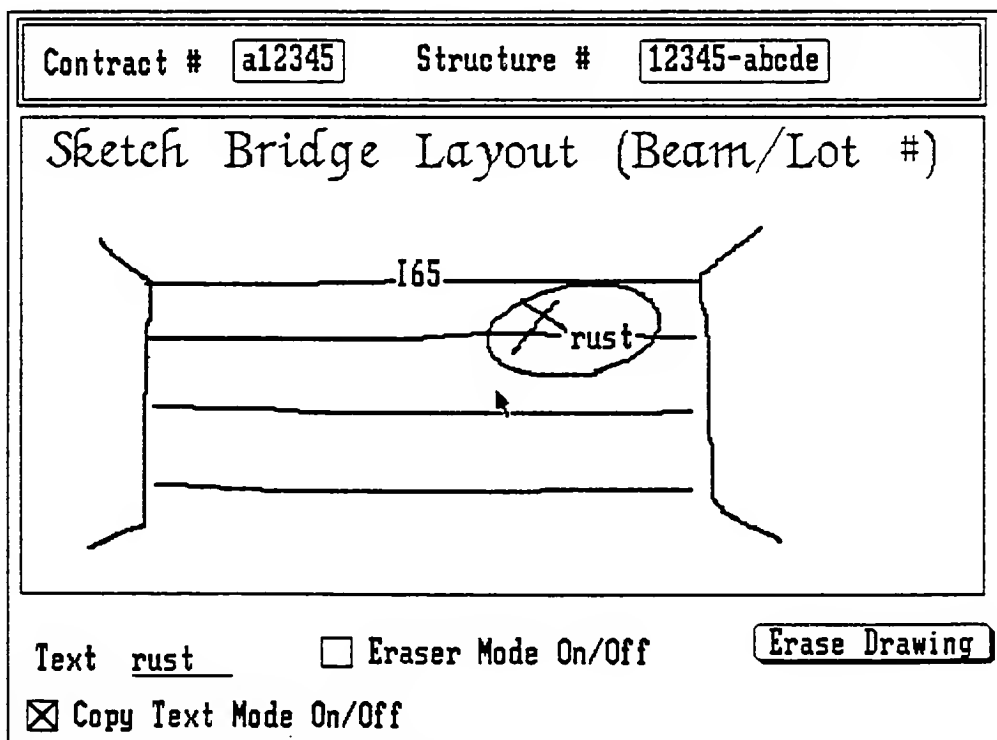


Figure 6.5 A defective area is marked on the PEPSI system

5. Allow Freedom to Navigate Among Forms

The PEPSI is designed to allow the users to jump among the inspection forms. During the course of a painting construction, the contractor may have two work teams for sandblasting and priming on different areas of the bridge at the same time. In this case, the inspectors need to efficiently flip among different inspection forms. Many control buttons in the PEPSI are designed to provide the users with freedom to navigate around different forms.

6. Incorporate with Decision-Making Algorithms

In the PEPSI system, the algorithm of the statistical acceptance sampling plan has been encoded into the system. Inspectors should just enter the measured data in the system, then the decision can be automatically made. This capability can break the barrier of applying advanced decision-making algorithms to construction sites.

6.7 Integrate Data Through Network

Currently, PCs have become the major environment where INDOT engineers handle daily data. Therefore, once the data are collected on construction sites, the data inside the pen-computers need to be transferred to PCs.

6.7.1 Data Transfer

There are many ways to transfer inspection data from pen-based computers to host computers. Selecting the best method of data transfer depends on how soon the data need to be processed. If the data must be processed as soon as possible, then real-time radio frequency data communication should be employed. However, for steel bridge painting inspection, the acquisition of inspection data does not have to be real-time between pen-computer and host computers. A serial RS-232 cable was proposed to transfer data from

pen-computers to PCs. Tremendous data transfer programs are currently available. Three popular data transfer programs were tested. The test results are described as follows:

1. Norton Commander

Data transfer is one function of the Norton Commander software. It requires several procedures to establish the connection. The complex setting procedures may confuse non-experienced users. A recent implementation in the Ryder's truck inspection project showed that users frequently got lost in the process of data transfer when using the Norton Commander.

2. LapLink

This is a high-end product for data transfer. It can use not only serial ports, but also parallel ports, to speedily transfer data. However, the program is complicated for non-computer-literate users.

3. InterLnk & InterSvr

This system consists of two parts: 1) InterLnk used in Master Computers, and 2) InterSvr used in Server computers. The InterLnk and InterSvr are the standard programs that come with the MS-DOS 6.0. This system is small but easy to use. Only two steps are required to link the sever to the master including: 1) typing "intersvr" in the pen-computers (server computers), and 2) typing "interlnk" in the PCs (master computers). After establishing the connection, the two computers are linked together like one unit. Users of the master computers, which are usually the PCs, can copy, delete, write, read, edit and run the files in the server computers.

Of the above three programs, the InterLnk and InterSvr are recommended for the INDOT because they are easy to use and come with standard MS-DOS.

The above programs can solve the problems of data transfer between pen-computers and PCs. But they have the limitation that a null modem cable is always needed to transfer data. It implies that the pen-computers and PCs must be at the same site within the short distances of the lengths of the cables. On many occasions, the data need to be transferred from job sites to the central offices. In this case, the above data transfer programs are useless. However, if the central office is equipped with a PCMCIA memory card driver, inspectors can simply send their memory cards containing inspection data to offices where data can be retrieved and integrated into a global database.

6.7.2 Needs for Data Integration

After inspection data are collected, they are only a bunch of non-related data. To fully utilize the power of the data, they need to be transferred to the central office for further integration. The inspection data integration provides valuable information for the central office to monitor quality at the job sites, the performance of contractors, and the work of inspectors.

6.7.3 Network Between Offices and Job Sites

There are basically three approaches to build networks for inspection data between job sites and the central office. They are:

- 1). Memory Storage medium,
- 2). FAX of the inspection results, and
- 3) PC to PC connection with modems through telephone lines.

Memory Storage Medium

Perhaps the easiest way to transfer data from construction sites to the central office is by sending memory storage media such as memory cards and floppy diskettes. To do so, the inspectors need to have spare PCMCIA flash-memory cards, and the central

office needs to have a PCMCIA flash-memory card driver. As an example, at the end of each project, the inspectors may send their PCMCIA card containing inspection results to the central office. In the central office, the data inside the memory cards are copied to a hard-disk of a PC. The hard-disk and PC then become a global database where the inspection results can be quickly retrieved. In this case, a hard-disk no less than 300 megabytes is recommended. According to recent field tests, one bridge usually requires around 70KB of memory. Based on the above configuration, one hard disk can store inspection data of around 5000 bridges.

Another option is downloading the data from pen-computers to PCs in district offices, copying the data onto a floppy diskette and sending it to the central office. In this way, the cost can be reduced because the storage medium is a floppy diskette, which is much cheaper than the PCMCIA flash-memory card. However, the inspectors need to learn how to transfer data between a pen-computer and a PC.

FAX the inspection results

In recent years, fax machines have become common in offices. Under certain circumstances, the central office may need to receive the inspection information rapidly. Faxing the data to the central office becomes a valuable approach, providing a fast hard copy of inspection results to the central office. To do so, the inspectors need to be equipped with a fax modem connected to the pen-computers. By programming approaches, the inspection data can be faxed to the central office in just a few minutes.

PC to PC Connection with Modems Through Telephone Lines

The memory storage approach has a drawback of long-updating period. It is difficult to quickly update inspection data by mailing memory cards or floppy diskettes. Faxing, the second approach, has two drawbacks. One is the expensive telephone fee and the other is the difficulty of database integration. One fax page usually takes a large

amount of memory, which costs significant telephone fees. Also, the non-electronic data (fax hard copy) can not be used in database integration unless they are re-typed into the computers. This not only takes more time, but also creates an opportunity for error.

Connecting PCs in the local and central offices through telephone network is recommended. To do so, both the inspectors and the central office need to be equipped with a high-speed modem. If a 14,400 baud protocol is used, the inspection data (around 70KB, equal to 20 pages of inspection forms) can be transferred in 1 or 2 minutes. This approach provides a timely and inexpensive way to transfer data. The above network for transferring data has been successfully tested in this research.

6.8 Trial of Pen-Computer System

The PEPSI system has been demonstrated to field inspectors. Feedback is summarized as follows:

At the beginning, some field inspectors balked at the idea of introducing computer technologies into construction sites, perhaps because many of them did not have much computer experience. When the PEPSI system was first shown to them, they were curious about what this toy could do for them. After a few trials, the PEPSI's user-friendly interface convinced the inspectors that the pen-based computer is a powerful tool in helping inspection data process.

Now, they like the unlimited pages of electronic forms. With this device, they do not need to carry many pages of paper forms. The sketch function is also preferable to help them record defective areas. The most attractive advantage is that they do not have to manage the paper forms as before. Using the conventional paper forms, they had to file the paper forms carefully. Sometimes, data recorded in the paper forms were missed. Now, all the data can be stored inside one unit: the pen-based computer.

However, some of inspectors were still frustrated by the handwriting recognition. The system has difficulty understanding some inspectors' handwriting. Although the simulated keyboard provides another alternative for data input, some inspectors were not familiar with the arrangement of the standard keyboard. Therefore, it took them a few seconds to find each key. Also, they complained that the pen-based computer is still too big and too heavy at construction sites. A smaller and lighter design is preferred. They were also worried about damage to the computer, in case they dropped it. Additionally, the contrast on the computer screen is not clear. The most serious problem was that sometimes they got lost when they tried to transfer data from the pen-computer to the host computers.

The general reactions from the inspectors are encouraging. The major negative responses were due to the hardware limitations. The concept and design of the software design were accepted.

Although the developed inspection computer software has been revised a number of times, continuous improvements are still needed before the software can be delivered to the users. Improvements in the software are made by testing the program in both INDOT's central office and at job sites. Appendix B shows the questionnaire used in the tests. The major revision tasks are described chronologically in Appendix C.

6.9 Advantages of the PEPSI system

The PEPSI system outdoes the traditional paper form with several advantages, summarized as follows:

- It provides an intuitive data input scheme such as handwriting recognition, pop up lists, and control buttons. With these input schemes even users without computer experience can operate the computers efficiently.
- It supplies a paperless work environment to field engineers and reduces the work load on data process. Thus, field engineers can spend more time on other critical tasks.

- It saves time by eliminating the requirement of double data entry -- from paper forms to computers. In addition, errors that occur when data is transferred from paper to computers can be reduced.
- It can apply advanced statistical processes such as the variable acceptance sampling plan. The advanced algorithm usually requires intensive computation, which is beyond the capability of most field inspectors. With the PEPSI system, the computation is all taken care by the computer.
- It reduces the required training time for new inspectors. The PEPSI is designed to provide a friendly input interface and detailed instruction of the inspection procedure.
- It facilitates the communication between the central office and construction sites by using electronic data communication. Thus, an integrated quality database can be established.

6.10 Extension To Other Highway Construction Inspections

The interviews with the field engineers revealed that the pen-based computer system can be applied to not only the steel bridge painting inspection, but also to many other inspections of highway constructions.

For example, the developed pen-based computer system can be applied to field inspection processes such as bridge deck corrosion and pavement inspections. A recent report showed that the Kansas DOT needs to gather approximately 8.5 million bits of information each year for their 20,500 bridges (Roads and Bridges, 1994). As another example, the INDOT needs to continuously process 11 pages of field inspection coding reports for each bridge. Therefore, the inspectors first need to fill up the inspection forms in construction sites, and then bring the data back to offices, and re-type the data into computers. The work involved is very time-consuming and may cause errors when the

data are re-typed into computers. If the inspection forms can be computerized through pen-technology, the required efforts can be reduced.

In another area, pen computing in CAD markets seems to be a natural evolution in the construction industry (Intorcio, John, 1992). The users can directly sketch markup in the field on their pen computers. For example, the inspectors may drawing an "X" over the defective beams that need repairing. Engineers checking field installations could carry pen computers on their arms rather than carrying rolls of detailed drawings. For instance, in a large-scale steel structure construction, thousands of steel members are piled on the job sites. The task to identify which steel members should be erected in which position is challenging work. Errors in this phase cause delay of construction. By linking pen-based computers and CAD, the field engineer simple write the code numbers of the steel members on the screen; the corresponding structure members will blink or change colors on the 3-D CAD model. If the field engineers do not understand the installation and connection among the members, they can zoom up the 3-D CAD model to get a close look at the designs.

Recently, expert systems are gaining in popularity. Several expert systems have been developed for highway construction, especially in the application of diagnosis. However, a computer is needed for expert systems to process algorithms and heuristic rules to generate solutions for human users. For instance, an expert system for concrete pile defect diagnostic has been developed. By inputting several inspection items into a computer system, the diagnostic results will be obtained (Yeh, Yi-Cherng.; Hsu, Deh-Shiu.; Kuo, Yau-Hwaug, 1991). Unfortunately, computers are commonly unavailable at construction sites. Without computers on hand, the inspectors must first write the inspection results on paper. Then the data is carried to offices where the computers and the expert systems are installed. Then the inspectors carefully type in the results of their inspection into the expert system. After obtaining the output from the expert systems, the inspectors bring the results and rush back to the construction sites, and pick up the

defective concrete piles. The project could be delayed because the inspection decision cannot be made right away. The inspectors need to take the trouble to travel between construction sites and offices. The whole process is inefficient. The cost to the contractors and the highway agencies increase, especially when the distance between available computers and construction sites is long.

A solution to the above dilemma is the pen-based computer. At the construction site, the field engineers can carry a pen-computer loaded with a related expert system. By writing down what they see, the pen-computer can respond to the diagnostic results right on the construction sites. The repair action may be taken right away. Significant savings can be achieved by reducing the delay of construction. With the availability of more powerful pen-computers, field engineers carry not only an electronic clipboard, but also a brain of experts for decision making. In summary, many other inspection processes are candidate areas for adapting the pen computing technology as long as they meet the following criteria:

1. **The INDOT would like to reduce the tedious paper works on the construction sites.**
2. **The INDOT would like to collect electronic data to build integrated databases.**
3. **The INDOT would like to apply advanced decision-making algorithms such as statistical acceptance sampling plan, neural network, and expert system on the construction sites.**

6.11 Potential Problems and Recommendations

Since the current inspection forms have not been formally written into the new specification, the developed pen-computer system cannot be fully implemented in field steel bridge painting inspection. Agreement between the central office and job sites is required before the electronic inspection system can be fully adapted. Currently, the most important task is to finalize the inspection forms. Only after the paper inspection forms are completely accepted can the pen-computer system be designed to match the final inspection forms.

Also, the field trial shows that users (inspectors) need to have a basic level of computer knowledge to operate the system. The bottleneck of the system has been found in data file transfer. Currently, data is transferred using a serial port. This requires users to have a certain level computer knowledge such as basic DOS command: "copy," "delete," "dir," and so forth.

Because of tough and harsh operating environments at construction sites, pen computers must be rugged and durable. Shock-resistance and water-proof standards must be improved.

Although the pen-computer can efficiently store a tremendous amount of data, it can also create a disaster for the INDOT if improperly used. It is not uncommon to hear that a computer hard-disk is mistakenly formatted, containing data of many years' hard work. Therefore, a foolproof file-backup procedure is critical.

This research shows that the elaborately designed pen-computer system is suitable for non-computer-literate users like most of the INDOT inspectors. With the experiences obtained in this prototype pen-computer system, the INDOT can efficiently expand computerized inspection to many other areas in the future. The benefit of computerization is not only on the time savings. In addition, the downstream benefits from the electronic data are important. Once the information is recorded electronically, the processing effort is made simpler. This project provides an automated system that stores all the information in

electronic format. No conversion effort is needed for downstream data processing. Moreover, with the power of computers, it can automatically make the decision to accept or reject the painting products.

In summary, a pen-based computer system will provide many benefits. Tedious paperwork can be reduced. The downstream benefits are valuable for electronic data integration. As a result, the collected data will be more accurate, providing the INDOT with more information to make better decisions. Before pen-computers really change the current data input practices, certain barriers must be overcome. The price needs to come down. The increasing competition and advancing technology will probably prompt the popularity of the pen computers. Handwriting recognition accuracy needs to be improved. It is of no doubt to the researchers that the explosion of computer technology will soon bring us more powerful and solid pen-computers with lower prices.

Chapter 7 Conclusions and Recommendations

The purpose of this research is to implement the steel bridge painting quality acceptance system developed in the previous research project (HJRP: HPR-2029-89-27) and to computerize the developed system into inspectors' daily practice.

7.1 Achievements of this Research

The research has accomplished several essential tasks that make the implementation of the new quality acceptance system not only possible, but also efficient. In summary, the research has achieved the following objectives:

1. An interactive computer graphic program was developed to assist the INDOT in designing the double sampling plan and deciding the sample size with controlled risks for both the INDOT and painting contractors. With this program, the sampling method can be updated to adapt to the evolution of new painting technology and new required quality levels in the future.
2. The training program was successfully conducted. Basic statistic and quality control concepts such as: lot, sampling size, single/double sampling, attribute/variable sampling, operating characteristic curve (OC curve), and producer's and owner's risks were introduced to the INDOT painting inspectors. The revised manual inspection forms were also presented. After the training program, the inspectors obtained better background in painting quality control and acceptance sampling system.

3. Field experiment of the developed inspection system was initiated immediately right after the inspector training program. The new acceptance system was manually tested. Feedback from INDOT's inspectors and other personnel were adopted to refine the inspection system.
4. A pen-computer system for painting quality acceptance has been developed. It can reduce both the need for inspectors' statistical background, and tedious manual paper work. The collected data will be more accurate, providing the INDOT with more information to make better decisions.
5. The electronic network system to transfer data between construction sites and the INDOT's central office was successfully tested. Once the data are collected on the field, the data inside pen-computers can be transferred to PCs in the central office. The communication between field and office was enhanced.

7.2 Recommendations for Future Work

According to the experiences obtained in this research, the following recommendations are proposed for future research.

1. Finalize the Inspection Forms

The new inspection forms have not yet been formally incorporated into official specification. Further communication between the office and job sites is needed to achieve a common agreement about the new inspection system.

2. Integrate Data Structure Between CRA and Pen-Based Computer System

The benefit of computerization is not only time savings but also improved information integration. Once the information is recorded electronically, the processing effort is made automatically. To optimize this benefit, further investigation is suggested to highly integrate the data structure of the pen-computer and the existing Construction Recorder Administration (CRA) database.

3. Continually Survey the New Computer Hardware

In this research, the preferable pen-computer has been selected. However, because of the tough and harsh operating environment at construction sites, pen computers need to be more durable and feature higher shocking resistance and water-proof standards. It is foreseeable that tight competition among pen-computer manufactures and the rapid advancement of computer technology will bring us more powerful and solid pen-computers with lower prices. INDOT should continually survey the new pen-computer technology before massive purchasing.

4. Conduct More Inspector Training Program

The field trial stage showed that the users need more computer knowledge to operate the developed system. More training is recommended. The short courses should be very helpful in strengthening inspectors' capability. The training program should focus on essential issues, such as how to make decisions to accept or reject a painting job, how to ask contractors to fix defective jobs, and how to process the inspection paper work.

5. Apply Pen-Based Computer Systems To Other Highway Construction Inspection Process

The pen-based computer system in this project can be regarded as pilot research for other INDOT's *field inspection processes*. This technology can be also applied to many other inspection areas, such as bridges and pavement inspections. Many current inspection works are very time-consuming and may cause errors when the data is re-typed into computers. If the existing inspection forms can be computerized through pen-technology, the required efforts can be reduced, eliminating paper shuffling. Further evaluation needs to be conducted for many other inspection processes that are candidate areas for adapting the hand-writing recognition technology.

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Appendix A Specification Summary

• Specification Summary

	Dauphin DTR-1	Fujitsu PoqetPad Plus	GRID PalmPad
List Price	\$2,500	\$1,995	\$2,895
CPU/Clock Speed	Cyrix 25MHz 486SLC	NEC 7MHz	NEC 10 MHz
Dimension (HWD inches)	1.25 x 9 x 5	1.25 x 9.65 x 4.5	1.9 x 9 x 6.2
Weight (pounds)	3.5	1.9	2.9
RAM (standard)	2MB	2MB	2MB
Display	6-inch Backlit VGA	640 x 200	640 x 400
Pen/Digitizer	Electromagnetic/ Codeless Pen	Contact Resistive Codeless Pen	Electromagnetic/ Codeless Pen
Hard Drive	20MB	None	None
PCMCIA	None	2 PCMCIA 1.0	1 PCMCIA 1.0
Operation System (Pen OS)	PenDOS, PenRight, Penpoint, Pen Windows	PenDOS, PenRight	PenDOS, PenRight
Company Information	Dauphin Technology (Lombard, IL) 800-7827922	Fujitsu Personal System (Santa Clara, CA) 800-831-3183	GRID System (Westlake, TX) 800-934-4743

Appendix B: Field Test Questionnaire for Pen-Computers :

1. Generally speaking, what do you think about the QA computer program? Is it user-friendly?
2. Do you think that the INDOT inspectors have enough background to operate the QA program including, DOS and pen-computers?
3. How long do you think it will take for a INDOT inspector to learn to operate the QA program?
4. What do you think of the operation of the pen-computers in the field? Is the GRID pad too big to operate? Any power duration problems? What is the battery life required (hours)?
5. Do you think if the GRID PalmPad were only half-sized it would improved the situation?
6. Did you try the equipment out doors? Is the LCD screen difficult to read?
7. Are there problems for writing recognition in the QA program? How do you solve the problem?
8. Do you think, it will be beneficial for INDOT to computerize the inspection system with PEN-Computers?
9. What are the advantages and disadvantages of using pen-computers in the field compared with paper forms?
10. What are the potential difficulties when INDOT tried to computerize the inspection in the fields?
11. How do you like the QA computer program? Please point out the items that need to be improved?
12. Do you recommend that INDOT use the pen-computer in the future for painting inspection data collection?
13. Look at the pictures? which computers (Fujitsu Poqet pad and GRID PalmPad) do you like?

Appendix C Major Revision Tasks Of The Pepsi System

May, 1993:

The QA painting inspection program was delivered to the central office for testing. In general, PCs instead of pen-computers will be the working environment in the offices. Therefore a PC version of the QA program was developed in a parallel version that is exactly the same as the program run inside pen-computers.

June, 1993:

After the QA program was tested for a few weeks, an interview was conducted. Feedback about using the QA program was collected to improve the level of user-friendliness and the functionality. A lot of advice was obtained, and several malfunctions were pointed out. The major changes of the program are summarized bellow:

- Structural numbers should become one sub-key field of contact numbers. Originally, the designed database used only a contract number as a key field to manage data. However, in the current system, several bridges with different structure numbers can be assigned under one single contract number. With the original database structure, different bridges under the same contract number can not be stored separately. To solve the problem, the database was redesigned. The redesigned database adds structure numbers as sub-key fields to contractor numbers.

The redesigned data structure stores the collected data in two levels. For level one, the database creates the sub-directory using the contract number as the

name of the sub-directory. Then the data that belongs to the same contact number are stored inside the same sub-directory. For level two, inside the same sub-directory, the structure numbers are attached to each filename to distinguish which structures (bridges) the data belong to.

- Malfunctions of the decision-making mechanism concerning the number of defect were found. They were to be corrected.
- The printing function did not work on INDOT office's EPSON dot printers.

July, 1993:

The improved QA program correcting the problems found in June's interview were finished and delivered for further test.

August, 1993:

A few minor changes were requested based on the test during July, 1993. The changes concerned the date display and need for more control buttons to navigate around the program. It was also reported that the printing function was fully tested and worked well in the INDOT's central office.

September, 1993:

The refined QA program, based on the test in August, 1993, was finished and delivered to INDOT's central office. Meanwhile, an interview was conducted with field inspectors. The program was introduced step by step to field inspectors. Also, the GRID HD, a larger pen-computer, was used in field testing.

The reason for using GRID HD (the larger pen-computer) instead of PalmPad (the smaller one) is because the GRID Co. was sold to AST Co. The company transition tremendously delayed the purchase of PalmPad. However, in order to coincide with the timing of field testing, the GRID HD (double the size of the PalmPad) was still used to start the field test phase.

In October, 1993:

After two weeks of testing, the field trial was finished. The responses obtained in the field testing are quite positive. A sentence from one inspector was: "The program works well; it had no problems that I could figure out." However, there are still a few points that need to be changed. The format of structure numbers varies from bridge to bridge. For instance, one bridge structure number can be 123-456-98-ABC, and another can be 11-23-78-XYZ. Originally, the template format in structure number is #####-AAAA (#: digital and A: alphabetical), designed under the instruction of the INDOT central office. Because the format of structure number is variable, the template design for structure number needs to be redesigned.

Appendix D

Steel Bridge Painting Inspection Training Manual

A. FOUR MAJOR INSPECTION STAGES

The inspection procedures for field bridge painting construction are divided into four stages including:

- (1) **pre-inspection**
- (2) **surface preparation inspection**
- (3) **primer inspection**
- (4) **top-coat inspection**

Figure 1 shows the relationship and order between painting and inspection.

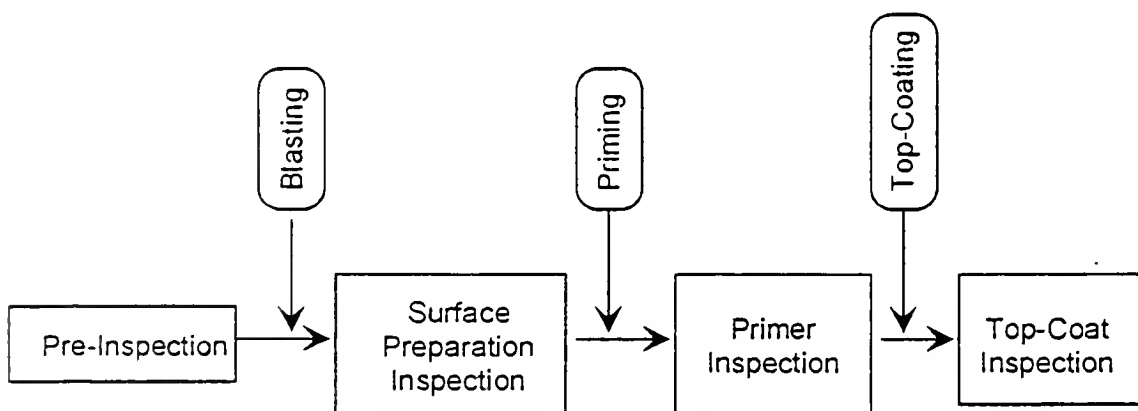


Figure 1 The Relation And Order Between Painting And Inspection.

B. INSPECTION FORMS OF THE FOUR INSPECTION STAGES

The followings are inspection forms for the four inspection stages. Form 1 is for the pre-inspection stage. Form 2 is for the surface preparation inspection stage. Forms 3-1, and 3-2 are for the primer inspection stage. Forms 4-1, and 4-2 are for the top-coat inspection stage.

FORM 1

Stage-I (Pre-Inspection For Painting)

Date _____

Inspected by _____

District _____ Structure _____

Contract _____

Contractor or Sub. _____

1. Has the contract of the project been reviewed? Yes No
2. Did the contractor submit
the paint manufacture's instructions? Yes No
3. Did the contractor submit
the application plan/schedule? Yes No
4. Has the traffic control and accessing plan been
discussed with contractors? Yes No
5. Is the following equipment ready to be use?

Psychrometer	Yes	No
US Weather Bureau Psychometric Tables	Yes	No
Surface Temperature Thermometer	Yes	No
Dry Film Thickness Gauge	Yes	No
Testex Micrometer with X-coarse Tape	Yes	No
SSPC Surface preparation Specifications (SSPC 1-89) ..	Yes	No
NBS Calibration Standard	Yes	No
Tape Measure	Yes	No
Flash Light	Yes	No

FORM 2**Stage-II (Surface Preparation Inspection For Painting)**

Date _____

Inspected by _____

Water Wash Cleaned. Yes No.

Time/Date of Wash _____

Solvent Cleaned Yes No.

Air Cleanliness Yes No.

Required Profile: _____ mils

Required Surface Cleanliness Grade: _____

<<First Sampling>>

Time/Date : _____

	Beam No. / Location	Profile Reading	Is SSPC Visual Cleanliness Grade OK?	
			Yes	No
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				

Number of Defect (x1=): _____ If (x1=0, 1) then Accept

If (x1=2) Take Second Sampling If (x1=3, 4, 5) Reject

<<Second Sampling>>

	Beam No. / Location	Profile Reading	Is SSPC Visual Cleanliness Grade OK?	
			Yes	No
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				

Number of Defect (x2=): _____ If (x2 = 0, 1, 2) then Accept

If (x2 = 3, 4, 5,) Reject

FORM 3-1

Stage-III (Primer Inspection For Field Painting)

Date _____

Inspected by _____

District _____ Structure _____

Contract _____

Contractor or Sub. _____

Cleanliness of steel surface before painting

(please check with a white napkin) Yes No.

Is the dry film thickness gage calibrated? Yes No.

Air-less spray?.....Yes No. if "No" air supply clean?Yes No.

Name of paint manufacturer _____

Batch # of paint: _____ and the amount _____ gallons used.

Paint material approved? Yes No.

Is paint well power mixed? Yes No.

Thinning approved Yes No.

Time/Date of priming _____

Time between blasting & priming _____ Hrs.(maximum 24 Hours)

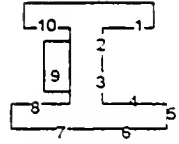
Did the contractor cooperate with INDOT by helping**inspectors access the bridge in primer inspection?..... Yes No.**

Daily working ambient condition:

Date					
Time					
Dry Bulb (F)					
Wet Bulb (F)					
Relative Humid.(%)					
Dew Point (F)					
Steel Temp. (F)					
Steel Temp.- Dew Point					
Wind Speed (MPH)					
Is the Ambiance OK? (Y/N)					

Weather Comments: _____

FORM 3-2

Required **Primer** Coating Thickness :

Is Visual Primer Inspection OK? Yes No			
Date of Measurement :		First Sample Beam/Lot#	Second Sample Beam/Lot#
	Location of Measurement		
1	bottom of top flange		
2	web		
3	web		
4	top of bottom flange		
5	vertical edge of bottom flange		
6	bottom of bottom flange		
7	bottom of bottom flange		
8	top of bottom flange		
9	diaphragm		
10	bottom of top flange		
Number of Defect =			
Accept		Reject	
Remark:			

Is Visual Primer Inspection OK? Yes No			
Date of Measurement :		First Sample Beam/Lot#	Second Sample Beam/Lot#
	Location of Measurement		
1	bottom of top flange		
2	web		
3	web		
4	top of bottom flange		
5	vertical edge of bottom flange		
6	bottom of bottom flange		
7	bottom of bottom flange		
8	top of bottom flange		
9	diaphragm		
10	bottom of top flange		
Number of Defect =			
Accept		Reject	
Remark:			

FORM 4-1

Stage-IV (Top-Coating / Immediate-Coating Inspection For Field Painting)

Date _____

Inspected by _____

Cleanliness of surface before painting

(please check with a white napkin) Yes No

Is the dry film thickness gage calibrated? Yes No.

Air-less spray?....Yes No. If "No" air supply clean? Yes No.

Name of paint manufacturer _____

Batch # of paint: _____ and its amount is _____ gallons.

Paint material approved? Yes No.

Is paint well power mixed? Yes No.

Thinning Yes No.

Time/Date of top-coating _____

Time between priming & top-coating _____ days

Daily working ambient condition:

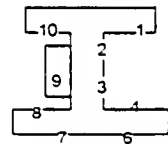
Date				
Time				
Dry Bulb (F)				
Wet Bulb (F)				
Relative Humid.(%)				
Dew Point (F)				
Steel Temp. (F)				
Steel Temp. - Dew Point				
Wind Speed (MPH)				
Is the Ambiance OK? (Y/N)				

Weather Comments: _____

Did the contractor cooperate with INDOT by helping

inspectors access the bridge? Yes No

FORM 4-2



Required Top-Coating Thickness :

Is Visual Top Coat Inspection OK? Yes No			
Date of Measurement :		First Sample Beam/Lot#	Second Sample Beam/Lot#
	Location of Measurement		
1	bottom of top flange		
2	web		
3	web		
4	top of bottom flange		
5	vertical edge of bottom flange		
6	bottom of bottom flange		
7	bottom of bottom flange		
8	top of bottom flange		
9	diaphragm		
10	bottom of top flange		
	Number of Defect =		
Accept		Reject	
Remark:			

Is Visual Top Coat Inspection OK? Yes No			
Date of Measurement :		First Sample Beam/Lot#	Second Sample Beam/Lot#
	Location of Measurement		
1	bottom of top flange		
2	web		
3	web		
4	top of bottom flange		
5	vertical edge of bottom flange		
6	bottom of bottom flange		
7	bottom of bottom flange		
8	top of bottom flange		
9	diaphragm		
10	bottom of top flange		
	Number of Defect =		
Accept		Reject	
Remark:			

C. DOUBLE SAMPLING METHOD

1. Lot

A "lot" is the basic unit of acceptance plans. Acceptance or rejection decisions are made within the lots. Currently, daily products are grouped as one lot.

2. Random Sampling

The measurements should be **randomly** taken for any sampling to obtain non-biased information. Theoretically, each measurement in a population has an **equal chances** to be taken.

3. Decision Tree for Double Sampling Method

Within a lot, 10 measurements should be "**randomly**" taken for the first sampling. If the number of defective measurements is 0 or 1, the decision is made to accept the lot. If the number of defective measurements is 3, the decision is made to reject the lot. If the number of defects is 2, a second sampling of 10 measurements is necessary. If the number of defects of the measurements in the second 10 measurements is less than or equal to 2, the decision is made to accept the lot; otherwise, the lot is rejected (Figure 2).

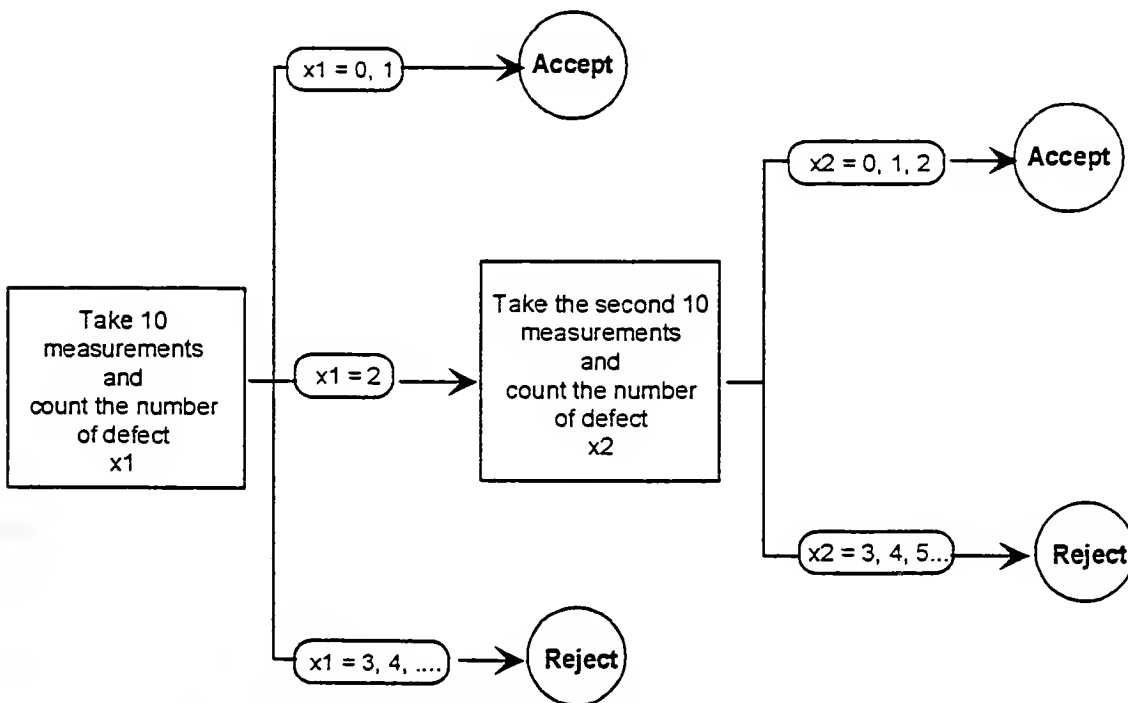
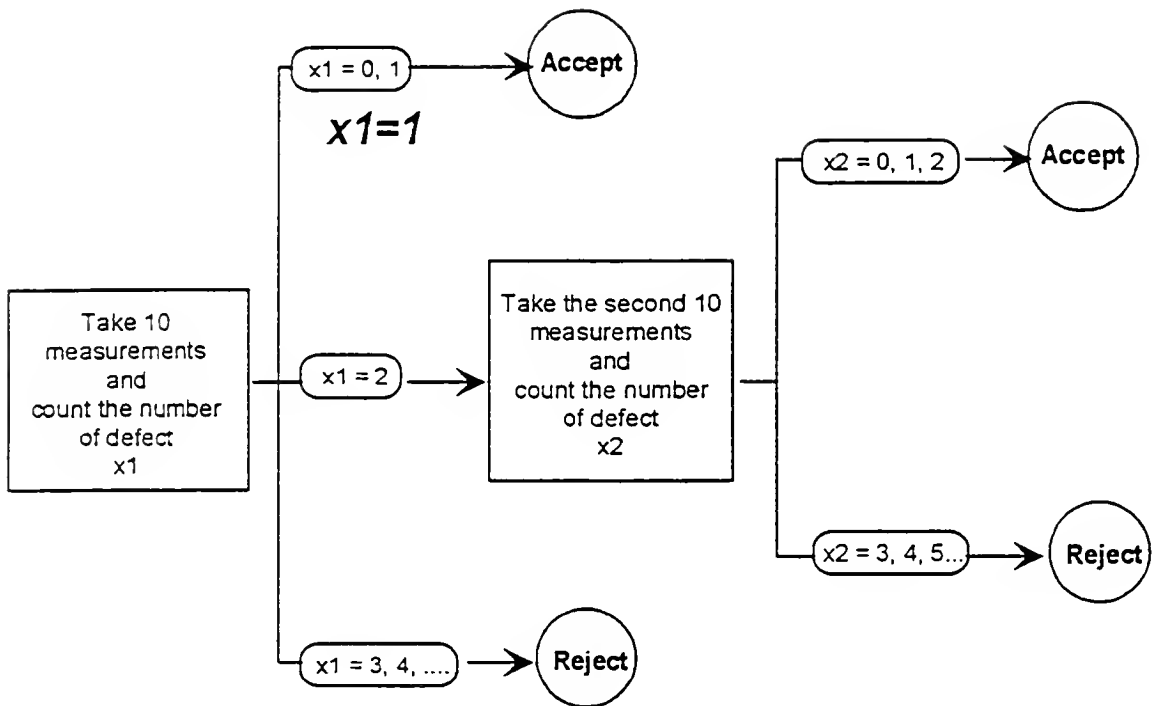
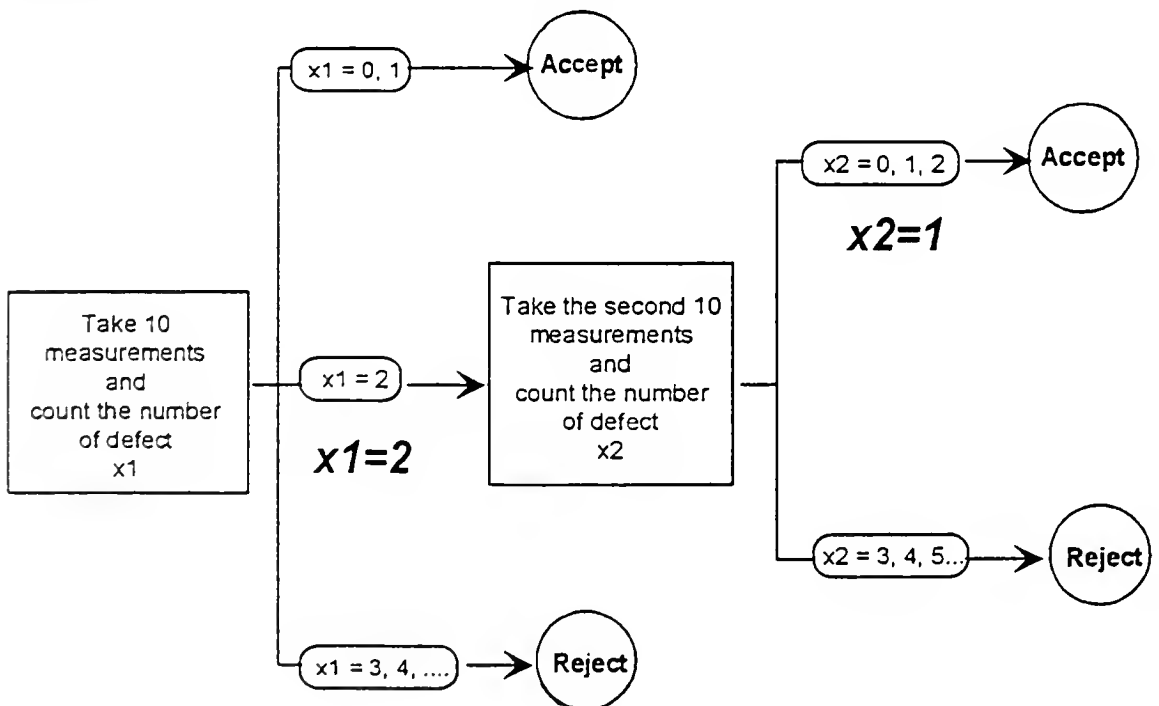
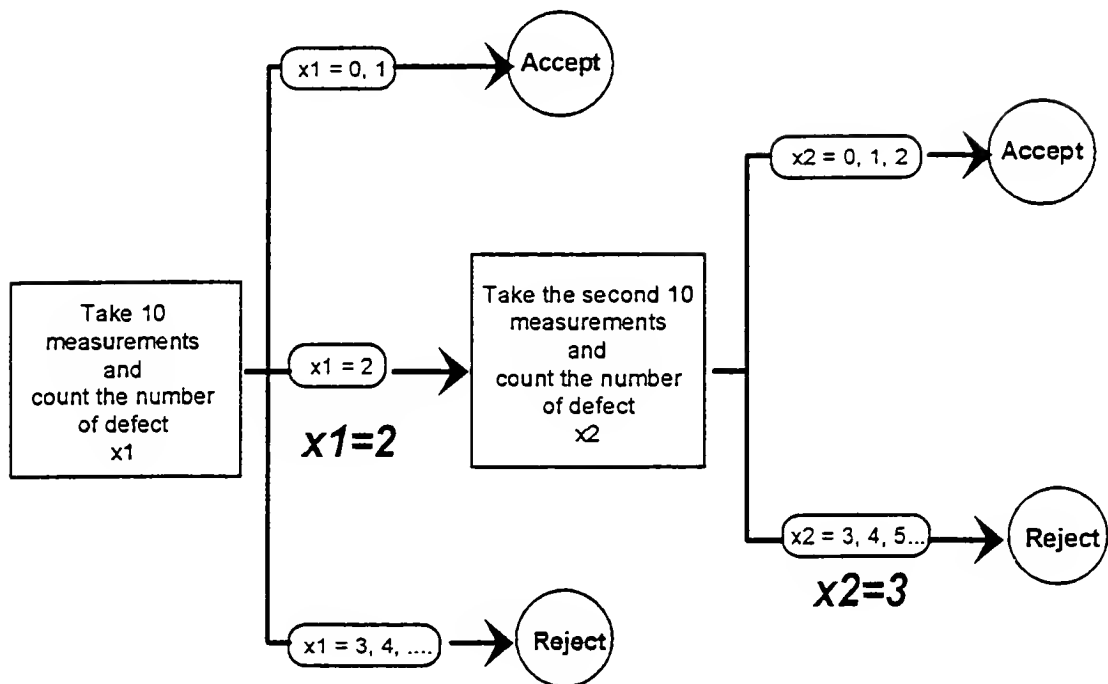


Figure 2: Decision Tree for Double Sampling Method

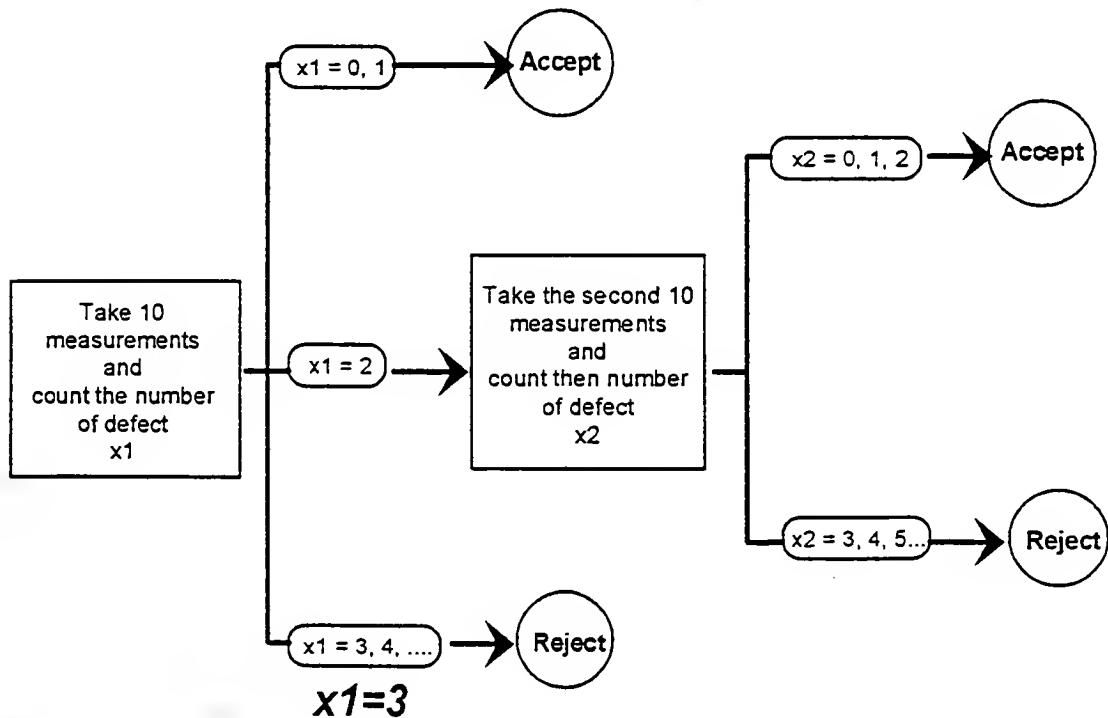
4. Example

example #1 $x_1 = 1$ example #2 $x_1 = 2 \implies x_2 = 1$ 

example #3 $x_1 = 2 \implies x_2 = 3$



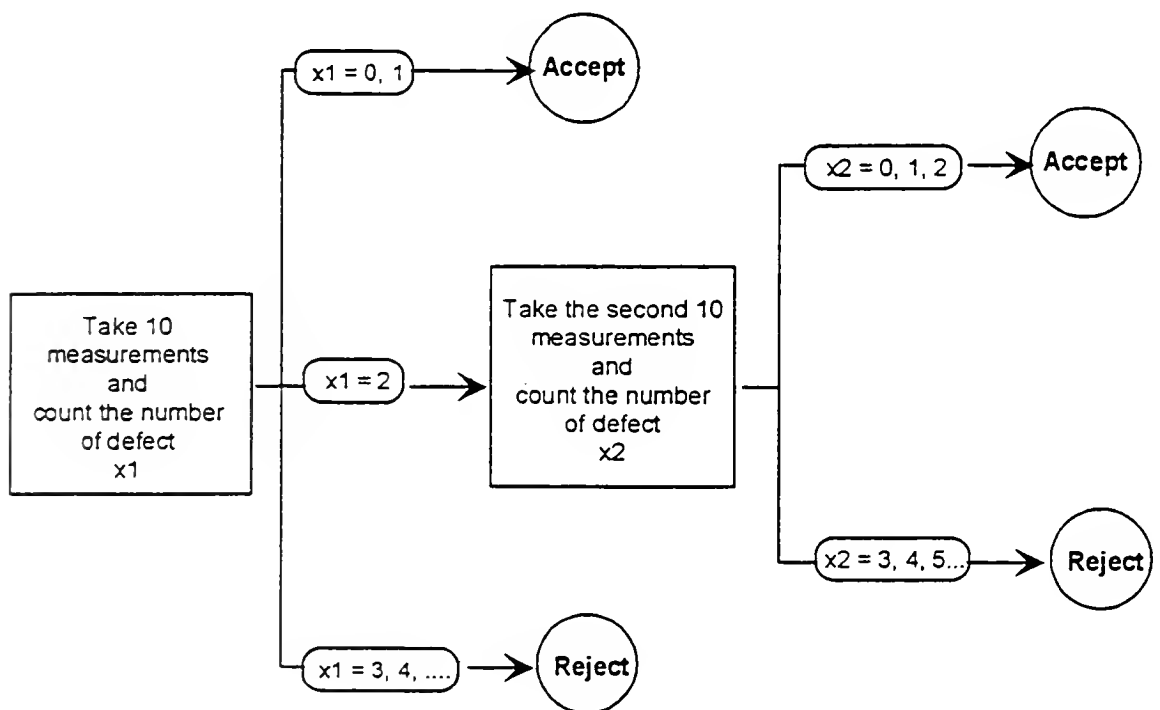
example #4 $x_1 = 3$



Exercise #1: Required Profile: 1.5 - 3.5 miles.

Please make decisions to accept or reject the lots.

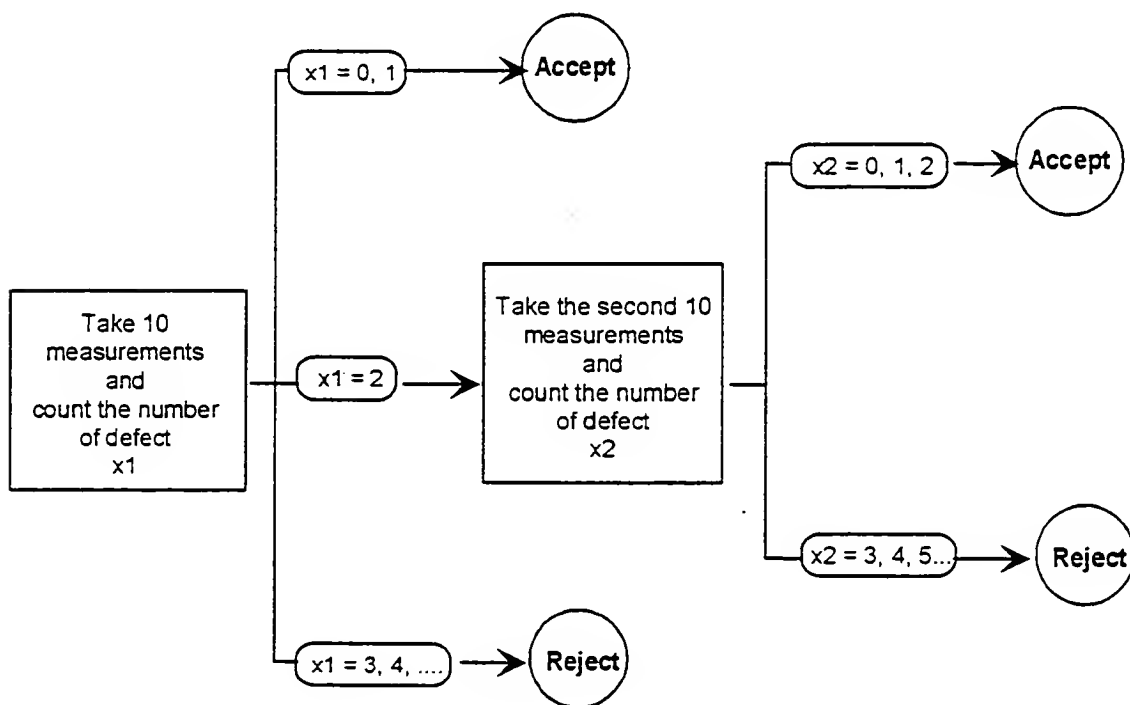
first sample	1.6	2.5	2.1	4.1	3.3	1.4	3.0	2.0	2.2	1.8
second sample	2.6	1.6	3.2	2.1	2.3	2.4	2.0	2.2	2.7	1.8



Exercise #2: Required Primer DFT: 2.5 miles.

Please make decisions to accept or reject the lots.

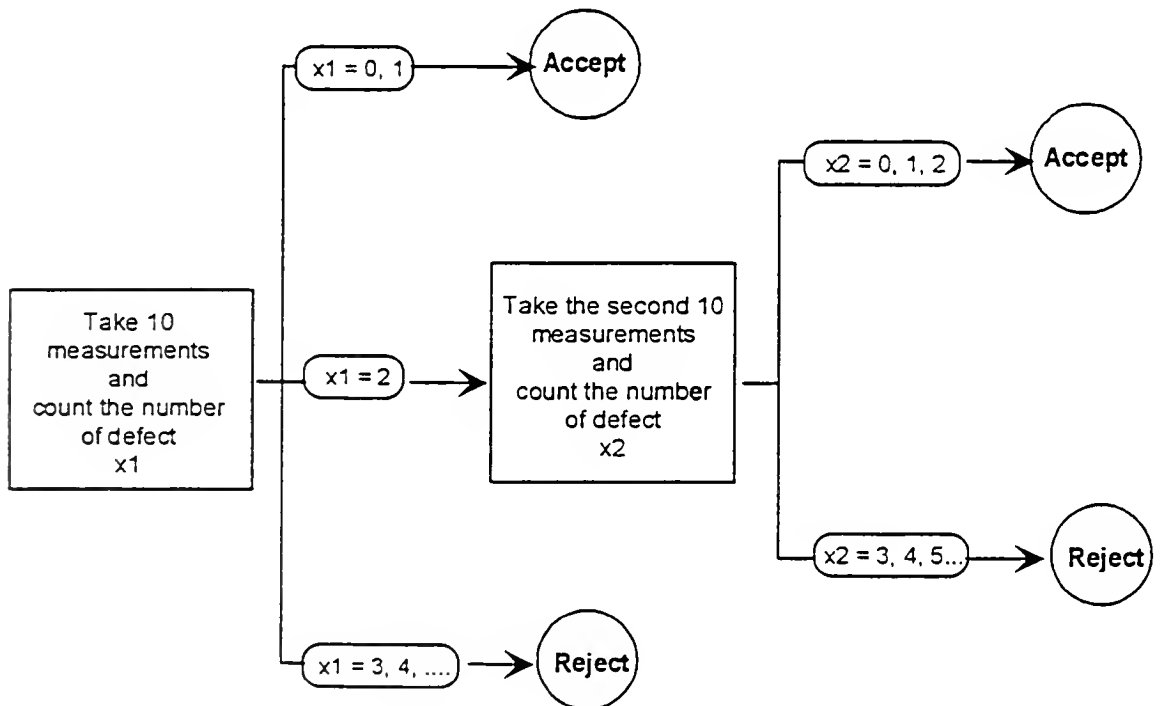
first sample	3.6	2.1	2.2	3.1	2.3	3.4	4.0	4.2	4.1	3.8
second sample	4.6	4.7	3.2	5.1	2.3	3.4	3.0	3.2	3.7	2.8



Exercise #3: Required Total Top-Coat DFT: 5.5 miles.

Please make decisions to accept or reject the lots.

first sample	6.6	6.1	7.2	6.1	5.3	6.4	6.0	6.2	6.1	7.8
second sample	5.6	6.3	7.2	8.1	7.3	5.4	6.0	6.2	6.7	5.8



D. Coding System For Beam Numbers

The coding system is used to specify the beam that is selected for testing. It consists of two major parts including: 1) the number assigned to the beams, and 2) the date of painting. For example, "11-12/05" means that beam number is number 11 and the date of painting is December 5th. Sometimes a long beam takes several days to paint. The code for date can be utilized to distinguish the date when the lot was painted. The number of beams could be coded from the North to South; or from the West to the East. Figure 3 illustrates some examples of the coding system.

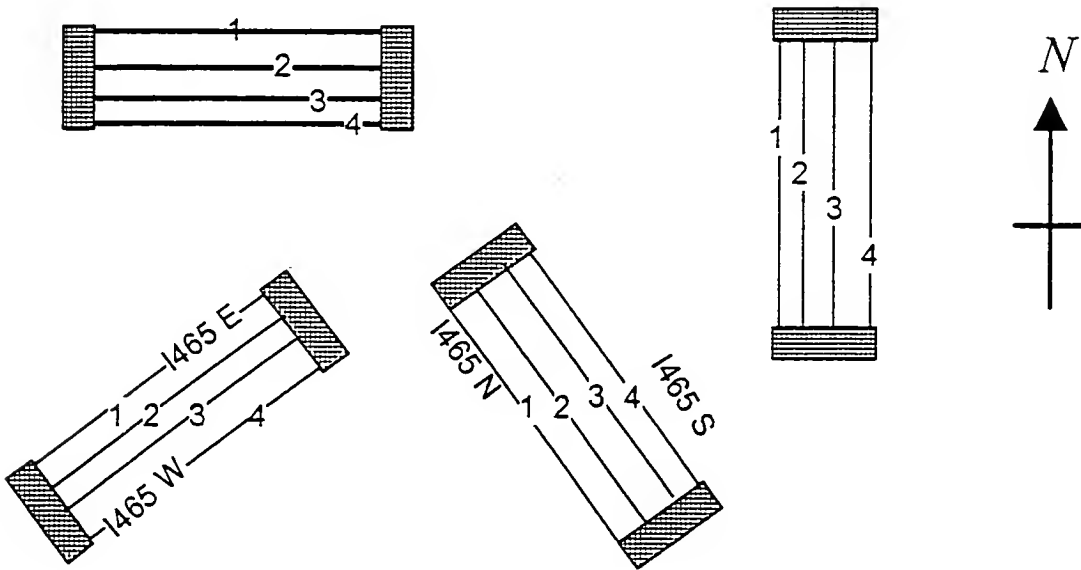
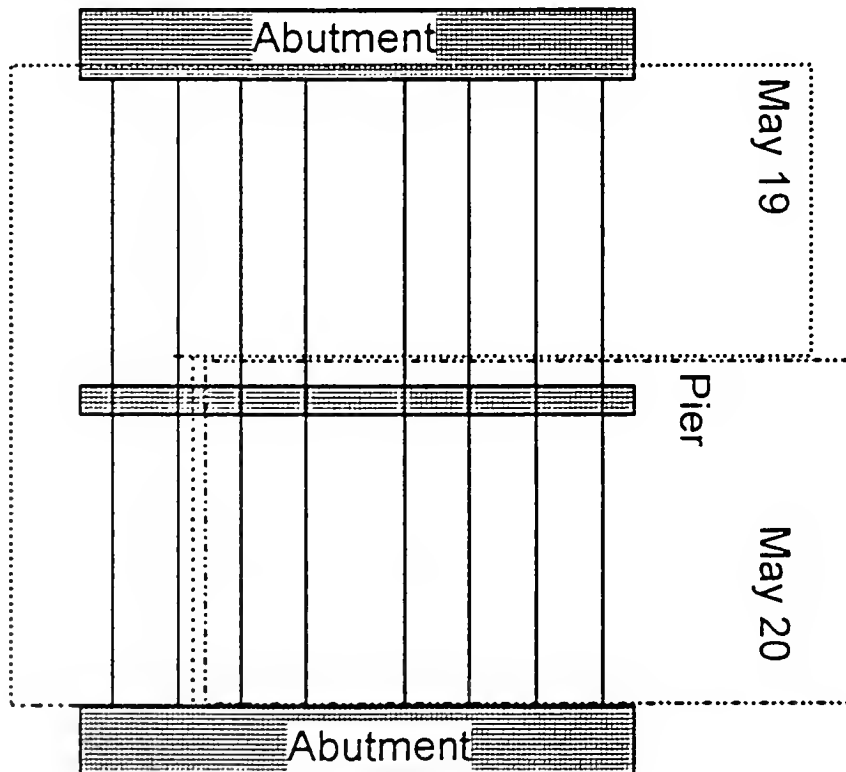
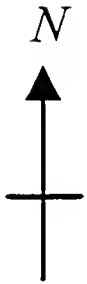
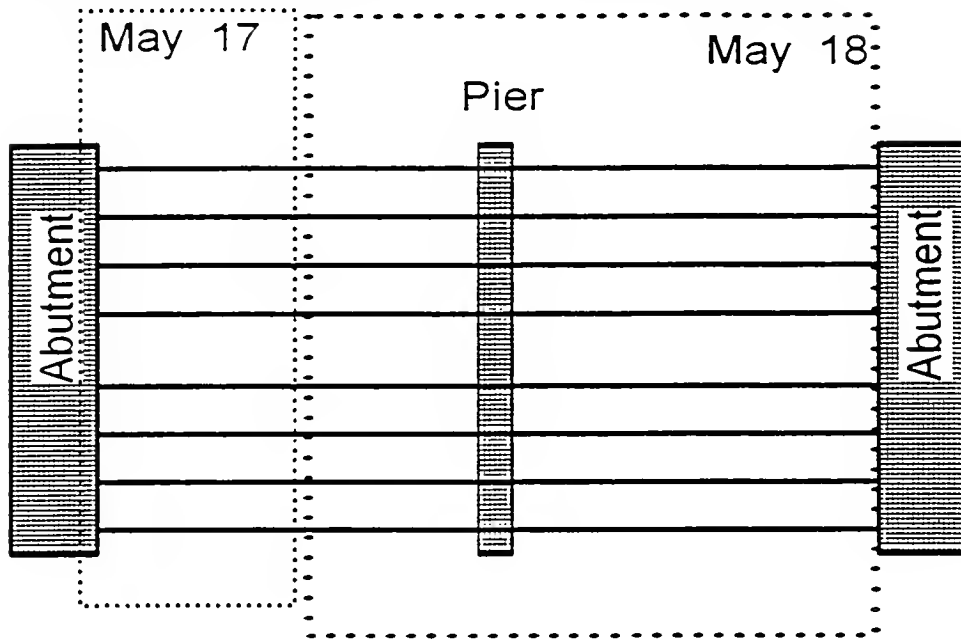


Figure 3 Beam Coding System.

Exercise #4

Please write the beam number (coding) in the following sketches.



E. CASE STUDY

The following case is used to illustrate the application of the inspection forms.

Background

On August 24, 1991, the steel bridge located at the overpass of Vermont Street and I-65 in Indianapolis, Indiana, was scheduled for painting. This steel bridge consists of eight I- shape beams structured in two spans. The configuration of the bridge is shown in Figure 4.

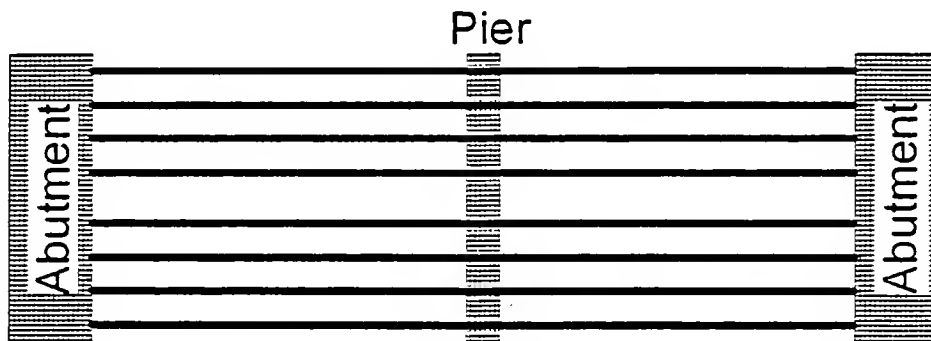


Figure 4

Stage -I: Pre-Inspection

Using Form I

The engineer, Steven, was taking charge of inspecting the quality of this painting project. The painting contractor, S.G. Company, planned to finish the surface preparation and priming in two days, on August 24th, and 25th. Three days after priming, the contractor planned to apply the finish coat in one day, on August 27th. The application plan, information about traffic control, and the brand of the proposed paint material used were submitted to Inspector Steven the day before application.

Meanwhile, Steven reviewed the contract and the application plan submitted by S.G. Company. He checked to make sure that the inspection equipment was ready to work. Form 1 was then filled in according to the completeness of the preparation. If the answer to the question in the checklist was yes, then "yes" was circled; if the answer was "no," the requirements had to be satisfied before the painting could be started. After all items on Form 1 were satisfied, Inspector Steven informed the contractor to start the work according to the plan. At this point, the Stage-II (Surface Preparation) began.

Stage-II Surface Preparation:

Using Form 2

In Stage-II, surface cleanliness, air supply cleanliness and profile were checked. The time of blasting (9:00 A.M., August 24, 1991) was recorded to make sure that the interval between blasting and later priming was less than 24 hours. The SP6 standard was required for surface cleanliness. The blasted surface was to have a profile between 1.5 and 3.5 mils. Based on the daily product, ten profile measurements (sample size) were first randomly taken from one day's product (August 24). The number of the defect items in the first sampling was 2. Following the algorithm of attribute double sampling, the second sample of 10 measurements was randomly taken from the same lot. The defect number from the second 10 measurements was 2, signaling to the inspector that the profile passed the test (refer to Figure 2). At the same time, the surface cleanliness grades, such as SP5, SP6 and SP10, were recorded. The **surface cleanliness** is one of the most important factors for painting quality. Meet the requirement of surface cleanliness is a must. The results must either meet or exceed the requirement; otherwise the products should be rejected. The bridge layout with the date of blasting is shown in Figure 5.

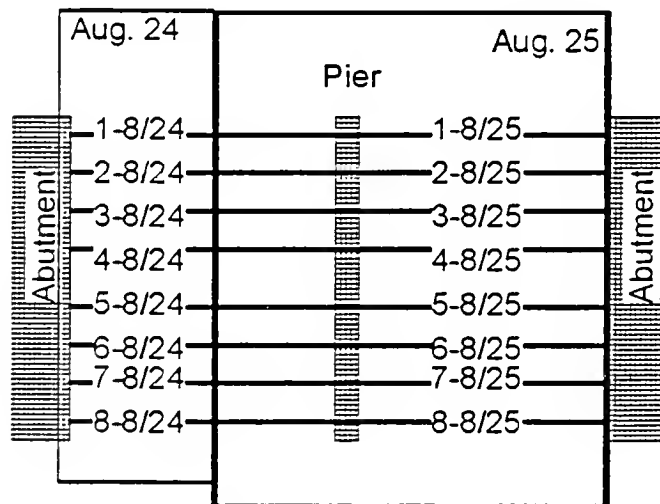


Figure 5 Bridge Layout with the Date of Blasting

Stage-III Primer Inspection:

Using Form 3-1

After each check item in the surface preparation was accepted, Stage-III started. The contractor planned to prime on the afternoon of August 24th. The label and batch number of the paint material were checked. Inspector Steven also checked the blasted steel surface by white napkin to make sure the surface was free of abrasives, dust, or

grease. However, when Inspector Steven measured the ambient conditions, it was found that the steel surface temperature (55°F) was not higher than the dew point (53°F) by 5°F. Consequently, the priming was stopped right away. At 2:00 P.M. on the same day, the previous ambient constraint was satisfied and the priming was then allowed to resume. The interval between blasting and priming was 6 hours, which fulfilled the criteria of being less than 24 hours (Form 3-1).

Using Form 3-2

After finishing the priming according to the specification, the contractor was asked to assist Inspector Steven to access the bridge for inspection. To record the inspection results, the beam numbers were coded by 1-8/24, 2-8/24, 3-8/24, 4-8/24, 5-8/24 and so forth. As mentioned before, the first digit stands for the beam numbers from the North to the South, and the rest of the codes indicate the application date (August 24th). The inspector **randomly** selected beam #5 for testing. In Beam 5-8/24, all of the 10 primer thickness measurements conformed with the requirement of a minimum of 2.5 mils, and the visual inspection was also satisfactory. As a result, the product of August 24 was accepted.

On August 25, no measurement was under the limit of 2.5 mils. However, dry spray was found visually by Inspector Steven in lot belonging to August 25th. Even though the quantitative dry film thickness (DFT) measurements passed the test, this lot was rejected because of dry sprays. Only after both the DFT and Visual Inspection requirements are satisfied can the lot be accepted. That is, if either one of the two requirements, DFT or Visual Inspection fails, then the lot fails. Figure 6 shows the bridge layout with the dates of priming.

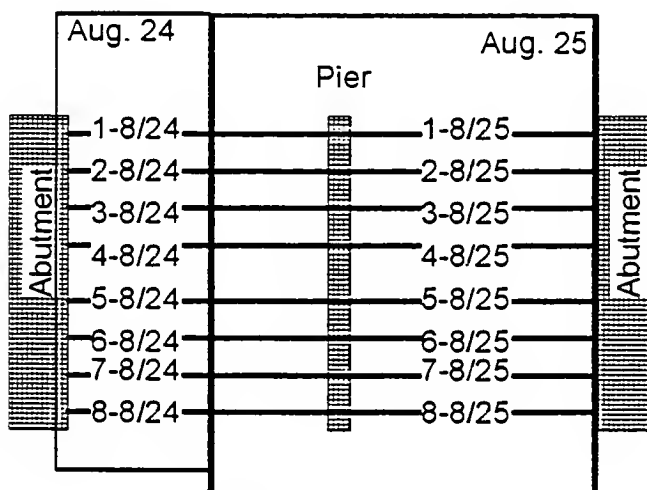


Figure 6 Bridge Layout with the Date of Priming.

Stage-IV Top Coat Inspection:

Using Form 4-1

All the rejected lots were repaired under the request of field engineer Steven and the defective work were redone before the day of top coating. Assume that a few days later, after all the rejected primed beams were repaired and accepted, the contractor then informed Inspector Steven that top coating would begin on the morning of September 1st.

However, at the job site, because the wind speed was reported to be as high as 25 MPH, Steven halted the top coating before it even started. At 1:00 P.M. on the same day, the wind speed slowed down to 10 MPH; the contractor then got permission to start the top coating (Form 4-1). Of course, before the painting, the label and batch number of the paint material were checked. The mixture of the paint material was also monitored carefully by Steven.

Using Form 4-2

After the top coating was finished and dried, the contractor assisted Steven in accessing the bridge. The top coating sampling plan was taken again. The procedure is similar to the primer sampling. Again, the lots were coded by 1-9/01, 2-9/01, 3-9/01 and so on. Figure 7 shows the bridge layout with the dates of top-coating. Beam # 8 in lot 9/01 was selected for testing. Two measurements were out of the limits: 5.5 mils. The second 10 measurements on beam #3 were taken. The number of defect of the second 10 measurements was 0. The lot of September 1 was accepted. For lot of September 2, no defective measurement was found, and the Visual Check was OK. The lot of September 2 was accepted.

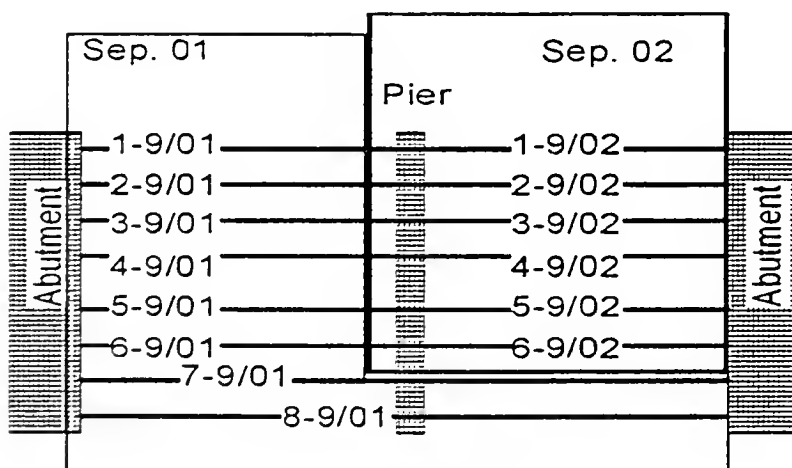


Figure 7 Bridge Layout with the Date of Top-Coating

Blank Forms

*** Please Complete Exercise on the Blank Form ***

FORM 1

Stage-I (Pre-Inspection For Painting)

Date _____

Inspected by _____

District _____ Structure _____

Contract _____

Contractor or Sub. _____

1. Has the contract of the project been reviewed? Yes No
2. Did the contractor submit
the paint manufacture's instructions? Yes No
3. Did the contractor submit
the application plan/schedule? Yes No
4. Has the traffic control and accessing plan been
discussed with contractors? Yes No
5. Is the following equipment ready to be use?

Psychrometer	Yes	No
US Weather Bureau Psychometric Tables	Yes	No
Surface Temperature Thermometer	Yes	No
Dry Film Thickness Gauge	Yes	No
Testex Micrometer with X-coarse Tape	Yes	No
SSPC Surface preparation Specifications (SSPC 1-89) ..	Yes	No
NBS Calibration Standard	Yes	No
Tape Measure	Yes	No
Flash Light	Yes	No

FORM 2**Stage-II (Surface Preparation Inspection For Painting)**

Date _____

Inspected by _____

Water Wash Cleaned. Yes No.

Time/Date of Wash _____

Solvent Cleaned Yes No.

Air Cleanliness Yes No.

Required Profile: _____ mils

Required Surface Cleanliness Grade: _____

<<First Sampling>>

Time/Date : _____

	Beam No. / Location	Profile Reading	Is SSPC Visual Cleanliness Grade OK?	
			Yes	No
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				

Number of Defect (x1=): _____ If (x1=0, 1) then Accept

If (x1=2) Take Second Sampling If (x1=3, 4, 5) Reject

<<Second Sampling>>

	Beam No. / Location	Profile Reading	Is SSPC Visual Cleanliness Grade OK?	
			Yes	No
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				

Number of Defect (x2=): _____ If (x2 = 0, 1, 2) then Accept

If (x2 = 3, 4, 5,) Reject

FORM 2**Stage-II (Surface Preparation Inspection For Painting)**

Date _____

Inspected by _____

Water Wash Cleaned. Yes No.

Time/Date of Wash _____

Solvent Cleaned Yes No.

Air Cleanliness Yes No.

Required Profile: _____ mils

Required Surface Cleanliness Grade: _____

<<First Sampling>>

Time/Date : _____

	Beam No. / Location	Profile Reading	Is SSPC Visual Cleanliness Grade OK?	
			Yes	No
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				

Number of Defect (x1=): _____ If (x1=0, 1) then Accept

If (x1=2) Take Second Sampling If (x1=3, 4, 5) Reject

<<Second Sampling>>

	Beam No. / Location	Profile Reading	Is SSPC Visual Cleanliness Grade OK?	
			Yes	No
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				

Number of Defect (x2=): _____ If (x2 = 0, 1, 2) then Accept

If (x2 = 3, 4, 5,) Reject

FORM 3-1

Stage-III (Primer Inspection For Field Painting)

Date _____

Inspected by _____

District _____ Structure _____

Contract _____

Contractor or Sub. _____

Cleanliness of steel surface before painting

(please check with a white napkin) Yes No.

Is the dry film thickness gage calibrated? Yes No.

Air-less spray?.....Yes No. if "No" air supply clean?Yes No.

Name of paint manufacturer _____

Batch # of paint: _____ and the amount _____ gallons used.

Paint material approved? Yes No.

Is paint well power mixed? Yes No.

Thinning approved Yes No.

Time/Date of priming _____

Time between blasting & priming _____ Hrs.(Maximum 24 Hours)

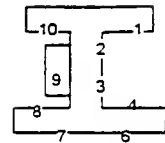
Did the contractor cooperate with INDOT by helping**inspectors access the bridge in primer inspection?..... Yes No.**

Daily working ambient condition:

Date					
Time					
Dry Bulb (F)					
Wet Bulb (F)					
Relative Humid.(%)					
Dew Point (F)					
Steel Temp. (F)					
Steel Temp.- Dew Point					
Wind Speed (MPH)					
Is the Ambiance OK? (Y/N)					

Weather Comments: _____

FORM 3-2



Required Primer Coating Thickness :

If Visual Primer Inspection OK? Yes No			
Date of Measurement :		First Sample Beam/Lot#	Second Sample Beam/Lot#
	Location of Measurement		
1	bottom of top flange		
2	web		
3	web		
4	top of bottom flange		
5	vertical edge of bottom flange		
6	bottom of bottom flange		
7	bottom of bottom flange		
8	top of bottom flange		
9	diaphragm		
10	bottom of top flange		
	Number of Defect =		
Accept		Reject	
Remark:			

If Visual Primer Inspection OK? Yes No			
Date of Measurement :		First Sample Beam/Lot#	Second Sample Beam/Lot#
	Location of Measurement		
1	bottom of top flange		
2	web		
3	web		
4	top of bottom flange		
5	vertical edge of bottom flange		
6	bottom of bottom flange		
7	bottom of bottom flange		
8	top of bottom flange		
9	diaphragm		
10	bottom of top flange		
	Number of Defect =		
Accept		Reject	
Remark:			

FORM 4-1

Stage-IV (Top-Coating / Immediate-Coating Inspection For Field Painting)

Date _____

Inspected by _____

Cleanliness of steel surface before painting

(please check with a white napkin) Yes No

Is the dry film thickness gage calibrated? Yes No.

Air-less spray?....Yes No. If "No" air supply clean? Yes No.

Name of paint manufacturer _____

Batch # of paint: _____ and its amount is _____ gallons.

Paint material approved? Yes No.

Is paint well power mixed? Yes No.

Thinning Yes No.

Time/Date of top-coating _____

Time between priming & top-coating _____ days

Daily working ambient condition:

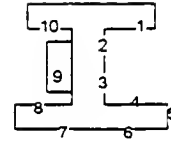
Date				
Time				
Dry Bulb (F)				
Wet Bulb (F)				
Relative Humid.(%)				
Dew Point (F)				
Steel Temp. (F)				
Steel Temp.- Dew Point				
Wind Speed (MPH)				
Is the Ambiance OK? (Y/N)				

Weather Comments: _____

Did the contractor cooperate with INDOT by helping

inspectors access the bridge? Yes No

FORM 4-2



Required Top-Coating Thickness : _____

If Visual Primer Inspection OK? Yes No			
Date of Measurement :		First Sample Beam/Lot#	Second Sample Beam/Lot#
	Location of Measurement		
1	bottom of top flange		
2	web		
3	web		
4	top of bottom flange		
5	vertical edge of bottom flange		
6	bottom of bottom flange		
7	bottom of bottom flange		
8	top of bottom flange		
9	diaphragm		
10	bottom of top flange		
	Number of Defect =		
Accept		Reject	
Remark:			

If Visual Primer Inspection OK? Yes No			
Date of Measurement :		First Sample Beam/Lot#	Second Sample Beam/Lot#
	Location of Measurement		
1	bottom of top flange		
2	web		
3	web		
4	top of bottom flange		
5	vertical edge of bottom flange		
6	bottom of bottom flange		
7	bottom of bottom flange		
8	top of bottom flange		
9	diaphragm		
10	bottom of top flange		
	Number of Defect =		
Accept		Reject	
Remark:			

F. FIELD INSPECTION SUMMARY

In this handout, the four stages of steel bridge painting inspection are described. The double sampling method is explained. The beam coding system is used to designate the locations of measurements. A case study is used to illustrate the application of the inspection forms. Figure 8 summarizes the whole inspection procedures.

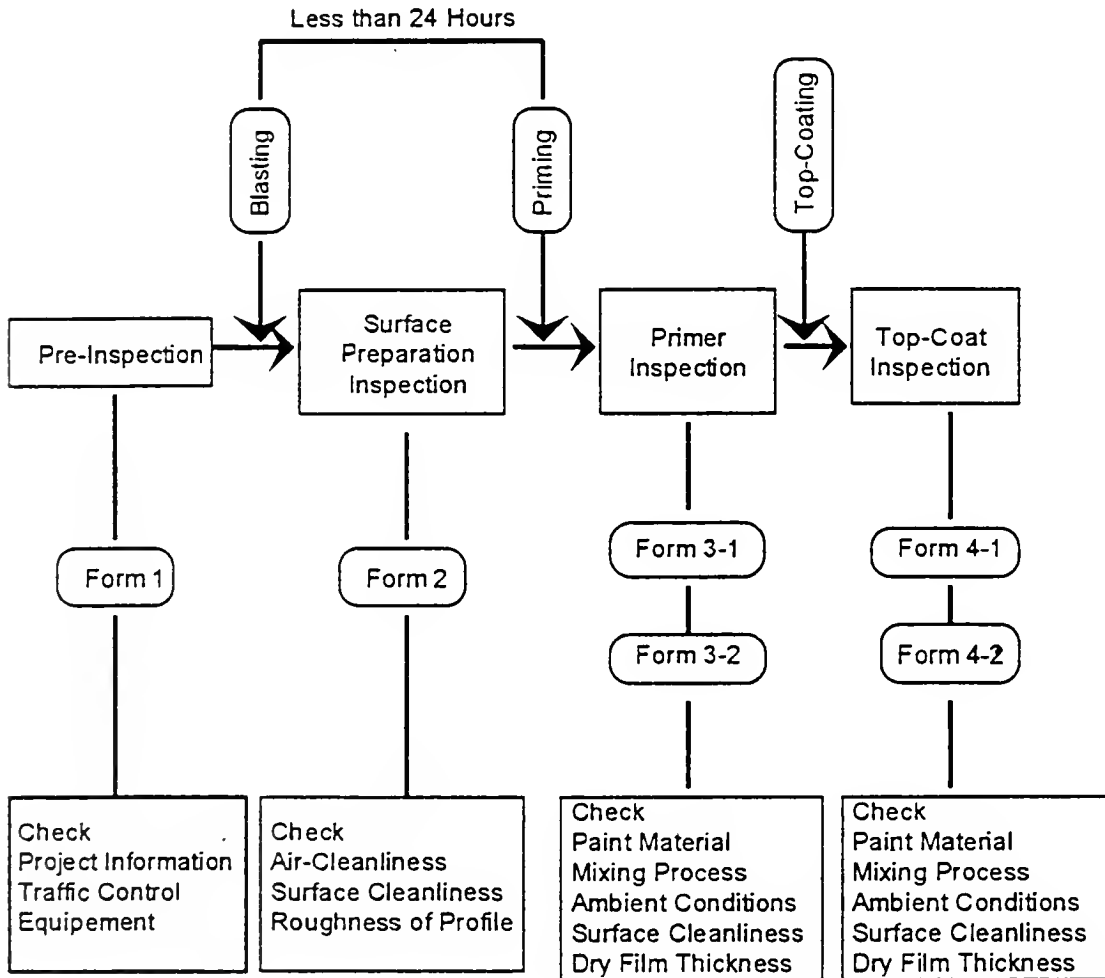


Figure 8 Summary of the Entire Inspection Procedures.

COVER DESIGN BY ALDO GIORGINI